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ABSTRACT

This literature review is the first phase of an extensive review of curriculum reform in science, mathematics and higher order thinking across the disciplines. The first of eight sections is an executive summary addressing the major themes of the document. The second section deals with several general issues of curricular reform concerning teaching and learning. The next three sections address separate aspects of school curriculum: mathematics, science, and higher order thinking across the disciplines. Each subject and section explores the historical context from which curriculum reform in this area emerges, characteristics of curriculum reform, required changes in curriculum, and current projects under way. The sixth section covers the process of curriculum reform. It is a multifaceted process that varies substantially from one time and setting to another. The next section addresses the context for reform in this country with attention given to national, state, and regional efforts at curriculum reform. The final section addresses the implications for the Curriculum Reform Project, for which this review of literature provided a foundation. A bibliography and a list of other Studies of Education Reform Program reports and a bibliography of 251 references are included (JPT)

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ISSUES OF CURRICULUM REFORM IN SCIENCE, MATHEMATICS AND HIGHER ORDER THINKING ACROSS THE DISCIPLINES

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INTRODUCTION AND EXECUTIVE SUMMARY

Under a contract with the Office of Educational Research and Improvement of the U.S. Department of Education, the University of Colorado is conducting an extensive study of curriculum reform in science, mathematics and higher order thinking across the disciplines. As a first phase of this project, an extensive review of the literature in this area has been made and is reported here.

This report is organized into eight sections, the first of which is an executive summary that addresses the major themes of the document. The second section deals with several general issues of curricular reform concerning teaching and learning. The next three sections address aspects of the school curriculum: mathematics, science and higher order thinking across the disciplines. Within each of these three sections attention is directed to such questions as:

- What is the historical context from which curriculum reform in this area emerges?
- What constitutes curriculum reform in this area?
- What changes are required for this curricular reform to occur?
- What reform projects are under way in this curriculum area?

Although these three sections of the review vary somewhat in format, in general they address these issues.

The sixth section of this report deals with the process by which reform takes place. To say "the process" is not intended to imply that there is some one way educational reform occurs. On the contrary, it is multifaceted, and the combination of facets varies substantially from one time and setting to another. On the other hand, there are some commonalities among successful change endeavors which will be addressed, in particular, their systemic character.

The next section addresses the current context for reform in this country, including the many organized actions in this area. Attention is given to national, state and regional efforts on the part of persons and organizations in both political and professional circles.

The final section of the report addresses implications of this extant literature for this project. It provided a partial basis for selecting topics for commissioned papers developed early in the project, knowledge that was incorporated into a national conference on curriculum reform and assessment held in June 1992, important understandings to be developed in "practical products" to be distributed to practitioners and policymakers at a later date, and most importantly, the beginnings of a conceptual framework for a series of case studies of curriculum reform to be conducted in selected U.S. schools.

Major Themes

Common Themes of the Reformers

The reviews of the research literature with respect to mathematics education, science education, and learning to think have produced some common themes.

Learning to think is an educational goal that extends across the disciplines with particular attention in the subject areas of science and mathematics. In contrast to some times in the past, it generally is regarded today as an essential goal for all students, not simply those going on to higher education. The research literature portrays this kind of thinking as being complex, not fully known in advance, often yielding multiple solutions, involving uncertainty, requiring nuanced judgments, and requiring considerable mental effort. It also must be done in a context; the subject matter of the school curriculum provides such a context. Students do not learn to think in the abstract; they learn to think with subject matter. Science and mathematics provide an excellent place in the curriculum for students to learn to think.

A second theme of the research is what is commonly called a constructivist approach to learning. In this view of learning, students are not passive recipients of information. Learning requires active involvement of the student in constructing meaning. Rather than just receiving more information, the learner must negotiate meaning with his/her learning community, make connections with past personal understandings -- modifying these prior conceptions if they are not accurate -- and build understandings that are part of that person's personal conceptual framework. These new understandings occur in a learning community or context; attending to context is an important consideration in fostering learning in science and mathematics.

Constructivist learning requires new approaches on the part of teachers. Rather than viewing students as passive recipients of information, teachers must focus on helping students construct understanding of concepts for themselves. Instead of spending time memorizing material, filling in blanks on worksheets, and repeating large numbers of similar problems, students need to solve novel problems, integrate information, and create knowledge for themselves. The teacher's role is to foster this hard work on the part of the student.

While the research indicates what such teaching involves, these findings are not as definitive as the findings pertaining to the learning itself; more is known about constructivist learning than constructivist teaching. In particular, this understanding of teaching is limited when considered in the context of classrooms having large numbers of students of diverse backgrounds and abilities.

A related theme often goes under the slogan, "Less is more." Some information is more important than other information in developing this sophisticated understanding of science and mathematics. It is not just a matter of learning more, it is a matter of learning that which will help build the desired overall conceptual picture. Encyclopedic learning of large quantities of information potentially can interfere with this selective learning of that which is of fundamental importance -- especially given the fact that some of these most important understandings are the most complex and require the most effort to learn. Effective learning requires focusing on the most important concepts and making the effort -- on the part of the learner -- required to build the necessary understanding. This greater selective attention to the most important conceptual understandings is the foundation of effective learning, thus the idea that "Less is more."

Significant curriculum reform is not possible without close attention to these basic principles of learning as shown by current research. As a result, current curriculum reform efforts such as Project 2061 of the American Association for the Advancement of Science (AAAS), the Scope, Sequence and Coordination (SS&C) Project of the National Science Teachers Association (NSTA), and the Standards of the National Council of Teachers of Mathematics (NCTM) all attend in substantial ways to this form of learning. Instead of presenting isolated facts, major attempts are made to focus on major themes of the subject matter and foster an integration of knowledge across the disciplines.

Making the Reforms Happen

Desiring certain reforms and making them happen are very different matters. The case for the desired reforms presented above has strong support in the research literature. On the other hand, the means by which these reforms can be attained is not so certain. There are many barriers to change and the strategies for overcoming them are not fully understood.

Barriers to change. Among the barriers to change are the beliefs and values on the part of everyone involved including the teachers, administrators, the community, and reformers themselves. A certain amount of consensus is needed for reform efforts to be mobilized effectively over the years of time required. The more diverse these beliefs and values are, the more difficult is change. Even if the reformers should agree on the matter of goals and the nature of learning and teaching, there is still the need for consensus regarding the means for reaching this new vision of education. Given the political context of reform efforts, it is clear that the lack of consensus among the public at large is a barrier to reform as well.

Diverse values and beliefs among teachers and administrators also are a barrier to change. A constructivist view of learning and teaching is far from universal among professionals in the schools. Furthermore, many professionals place socialization goals above intellectual development goals (Stake & Easley, 1978).

Similarly, student expectations are a barrier. Many students, often those who are most successful in the current system, resist changing from a predictable process in which they know how to succeed to one which fosters intellectual development in a context of some uncertainty, problems with multiple solutions and a lack of specific directions as to what to do.

Even if there is an adequate consensus vision of what education should be on the part of everyone involved, change is not assured. Change is not easy; in particular, changes in the roles of people are difficult. It is not easy for teachers to 'earn the new roles required of those who want to foster constructivist learning among students. It is not easy for students to overcome passivity and learn the needed role as a responsible and proactive learner.

Another barrier to reform is the lack of compatible instructional materials. None of the major science and mathematics education reform efforts of the AAAS, NSTA, or NCTM have produced curriculum materials for use with students. Although there is a limited patchwork of such materials -- some developed by recent National Science Foundation funded projects -- none of the nationally recognized efforts of AAAS, NSTA, and NCTM as yet have produced comprehensive curriculum models and related teaching materials for students.

All of the barriers described above exist within powerful institutional and cultural constraints. While the problems of bureaucracies, limited budgets, assessment practices, and rigid regulations are well recognized, the cultural constraints are at least as powerful, but often less visible. The commonly accepted values, beliefs, and practices of the society found within a given school or community form a common culture which typically is a powerful constraint to change.

There are many barriers to educational reform; change clearly is difficult. It requires resources, commitment, knowledge, and skills. Moreover, success depends upon applying them in the correct setting with appropriate timing. It is this approach to change which needs further attention.

The process of change. The process by which change occurs varies greatly from one setting to another and from one time to another. Although certain generalizations appear to apply to successful change endeavors, there is no particular set of processes (plural) to apply to ensure success. The overall process (singular) varies greatly but there are some important understandings that seem important to success.

First, a systemic outlook is essential. All efforts to introduce new instructional approaches, new curriculum materials or instructional goals demand such actions as inservice education for teachers, discussions with parents to develop consensus on goals and new directions, and leadership from administrators. Change requires attention to the subcultures of students, schools, and communities. None of these actions by itself is sufficient. All of them together may not work if initiated without consideration for how they interact with each other. Understanding the situation systemicly requires attention to psychological, philosophical, sociocultural and subject-matter perspectives (Anderson, 1992). It requires attention to organizational and political considerations. Actions taken at the national, state, district, school, and classroom levels, for example, can interact to support change in a common direction, or they can counteract each other in such a manner that change is defeated. And even though all actions taken are complementary, there is the possibility that the omission of some particular action or actions could stall what would otherwise be a successful reform effort. A vision of what should be must be combined with a systemic process of working toward that vision.

Second, positive and lasting change requires empowerment of teachers and an opportunity for them to develop their professional competency. Constructivist learning demands constructive teaching. Such substantial change demands that teachers be empowered to develop their professional competencies. In effect, teachers need to construct new understandings of their role and develop the ability to incorporate these new understandings into their actions as teachers and to become reflective learners themselves. These new changes need to be reaffirmed by the development and use of constructivist assessments to support the changes in materials and teacher development.

Third, such fundamental and far-reaching changes imply significant changes in the culture of the schools. It means new roles for teachers, students, parents, and administrators. More collaboration among teachers and new responsibilities, for example, may emerge as important elements in this changed culture. Such changes demand a systemic outlook that causes individuals to reassess values and beliefs pertaining to education.

There are many strategies & processes which research (Fullan and Stiegelbauer, 1991) indicates are part of such a systemic approach. They are important to successful reform. This research has many facets and deserves close consideration. This consideration, however, must take place within the framework of systems thinking and an organizational context that is growing (Senge, 1990).

Implications of the Research Literature for the Project

The research reviewed here has implications for the topics of commissioned papers selected for development, the character of the national conference on curriculum reform and assessment to be conducted, the topics to be developed as "practical products" for practitioners and policymakers, and, most importantly, the conceptual framework to be developed for a series of case studies of curriculum reform to be conducted in selected U.S. schools. With respect to these case studies, the following are particularly significant implications.

1. One should not expect school sites with fully implemented reforms to serve as the subject of study for these case studies. The process of reform is long enough and the efforts have been initiated recently enough that it is unrealistic to expect that examples of fully installed reforms are ready for study. Case studies of reform are valuable and available, but of necessity, they almost certainly will still be in process to some extent.

2. It is essential that these sites be studied from a systemic perspective.

3. It is essential that these sites be studied from multiple perspectives, i.e., that they be examined through the eyes of a philosopher, psychologist, sociologist, anthropologist, political scientist, organizational specialist and subject-matter specialist. The complexity of the situations under study demands these multiple perspectives.

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The research reviewed here also suggests several key questions which must be pursued in the case studies. Among them are the following:

1. What are the key elements of constructivist learning in the various subject areas as encountered in classrooms where reform has occurred?

2. What are the key elements of constructivist teaching in these same circumstances?

3. In successful curriculum reform endeavors, what are the key elements of a systemic approach?

The Literature Review Process

Because this literature is very extensive and several facets previously have been reviewed in a competent manner, the first step throughout has been to consult other reviews. As a result, reference often is made to such reviews as an overall picture is painted of what research has to say about curriculum reform in the areas under consideration. Where such reviews have not been conducted, or are somewhat dated, and where connecting information is needed, the research literature has been searched following standard procedures.

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CURRICULUM REFORM: GENERAL ISSUES CONCERNING TEACHING AND LEARNING

Several common themes have emerged from a review of the subject matter literature. Both science and mathematics education stress many of the same concepts emphasized in the literature about thinking skills across disciplines. The three most critical issues from all three of these areas are

1. All students need to develop higher order thinking skills.

2. Student learning is not a passive activity in which teachers disseminate knowledge to students, but rather it is an activity in which students must actively construct their own knowledge through a complex process of interaction with their own knowledge structures, engagement with the materials and attention to the dialogue through which they develop meaning.

3. Learning a lesser quantity of information in greater depth is preferable to covering large numbers of facts and concepts with little or no student understanding, commonly referred to as "Less is more."

These three themes will be covered in some depth here with limited reference to them in the following subject matter sections to emphasize differences between the general picture and the specific subject matter orientation.

Developing Thinking Skills

A variety of books exist that depict the major advances in understanding of how humans think and learn to think. During the 1980s and 1990s several books were published that make the arguments for change in how learning occurs, the basic argument being one of moving away from learning as simply recording or memorizing information and responding in a rote fashion to one of using and interpreting information. For further elaboration of one or more of these themes, the reader is encouraged to look at the following references: Nickerson, Perkins, and Smith, 1985; Chipman, Segal and Glaser, 1985; Segal, Chipman, and Glaser, 1985; Resnick, 1987; Baron and Sternberg, 1987; Resnick, 1989; Marzano Pickeray, and Brandt, 1988; Stiggins, Rubel & Quellmalz, 1988; Resnick and Klopfer, 1989; Kuhn, 1990; Presseisen, 1987; Suarez, Mills and Stewart, 1987; Sizer, 1984; Anderson, 1990; Banathy; 1991; Means and Knapp, 1991. The combination of these references will lead one to a variety of other sources and will allow the reader to construct his/her own understanding of teaching thinking across disciplines. The picture of this literature presented below contains eleven themes which appear to dominate modern research and practice related to teaching thinking across disciplines.

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1. It is no longer considered acceptable to have an education system that sorts and selects students for different roles in society. Until early in the twentieth century, schooling in the United States was divided into two traditions (Resnick, 1987). One tradition, concerned with elite education, had a selected clientele drawn largely from privileged social strata. The minority of students who attended these selective institutions had usually demonstrated a liking and an ability for intellectual pursuits. These schools emphasized reasoning, textual criticism, mathematical and scientific thought and other skills that today would be referred to as higher order thinking skills.

In contrast, the other tradition, referred to as the mass education system, was devised to provide the general population with the basic skills of reading, computation, health education and citizenship training. "Mass education was, from its inception, concerned with inculcating routine abilities" (Resnick, 1987, p. 5).

The growth of the population of secondary students after the turn of the century caused the distinction between the two traditions to become blurred. "Responding to changing economic and social conditions, more and more young people began to seek high school education, and educators gradually began to treat secondary education of a much larger and more varied population as being their proper concern" (Resnick, 1987, p. 5).

The historical context of the two traditions makes comprehensible the ongoing debate about whether there should be a common curriculum for everyone or different programs for students with different interests, goals and abilities. It also puts in perspective the seemingly contradictory nature of reforms of the last 20 or more years. For example, alternating reforms, which favor first the common curriculum and then the differentiation of courses, appear to be attempts to resolve the dilemma imposed by the conflicting values of excellence and equity in providing an equal education to all students (Cuban, 1988).

2. Broad conceptions of thinking and knowledge acquisition are changing. Many researchers and theoreticians are working to clarify the nature of thinking and describe it in such a way that educators can determine how to teach it. The move is away from a behaviorist perspective to a cognitive psychology perspective that holds that "learning occurs not by recording information but by interpreting it" (Resnick, 1989, p. 2).

Throughout most of the 20th century the dominant belief was that thinking ability is a simple consequence of intelligence. The notion was that the more intelligent an individual the greater his or her ability to think, and intelligence was generally thought to be a trait that could not be changed. During the last few decades, cognitive psychologists have strongly challenged this belief. They are taking the position that intelligence as measured is more a consequence of thinking ability than a cause, thinking ability and intelligence are overlapping but separate, and that thinking can be enhanced and taught (Nickerson et al, 1985).

Such research is leading to the belief that learning is about "sense making" or constructed knowledge. Learning occurs by interpreting information, not by recording it, and is dependent upon the intentions, self-reflections, elaboration, and mental images and experiences of the individual learner (Resnick, 1989, p. 2). Constructed knowledge emphasizes the active nature of learning and the interaction of external and internal factors; it is characterized by understanding and personal growth. It is the essence of students learning to think.

The growing body of research on learning to think places emphasis on the mental processes humans use to integrate new information and experiences with what they already know. This may include the reorganization of concepts to accommodate new experiences, but it may also involve the alteration of perceptions to make them compatible with existing concepts. Rather than filling mental rooms with facts "we constantly rearrange the walls and change the shape and contents of the rooms. Sometimes it seems that we start over from scratch. Yet, after each addition and reorganization we still have the original materials, which we put to new, broader uses" (Oakes & Lipton, 1990, p. 40).

As the concepts of intelligence and learning to think are separated, educators are coming to realize that all children can learn. Learning beyond rote is becoming recognized as something that should be available and possible for all students, not just a few.

The combination of the shift in understanding of thinking along with the social pressures to help all students learn to think have converged to move forward significant change in schools away from a rote learning approach to an emphasis on learning to think.

3. Conceptions of teaching are changing. Either with a new view of learning as described above or simply by observation of the dynamics between teachers and students in classrooms, a number of researchers are directing their attention to the dominant modes of instruction in the schools, asking whether these modes of instruction are indeed best to help students learn. A major shift is being encouraged away from an instructional method dominated by delivery of information to one in which the student is an active worker with the teacher being more of a coach and facilitator of learning (Sizer, 1984).

Instructional methods within the traditional education system have viewed the learner as a passive recipient of information, an empty vessel to be filled or a sponge waiting to soak up knowledge. Under the old -- but still predominant today -- model of education, classrooms are characterized by the teacher being in charge; they are dominated by one-way transmission of information from the teacher to the whole class (Goodlad, 1984; Sizer, 1984).

Most metaphors used to describe learning refer to it as delivered and externally controlled (Reddy, cited in Iran-Nejad, 1990). "Delivered knowledge" is characterized by an accumulation of facts, memorization for later reproduction and preparation for tomorrow.

Others approach the issue by making a distinction between training (which prepares people to respond appropriately to events and needs) and sense making (which enables people to construct individualized meanings and responses to their experiences) (Oakes & Lipton, 1990). Training, based on the behavioral approach to learning, works for certain types of tasks such as memorization. An over-emphasis on the behavioral approach to learning in schools, however, influences our view of the learner and the teaching process and leads people to assume that the behavioral approach is best. Combined with the view that children are empty vessels to be filled or sponges waiting to soak up knowledge, this view supports much of what currently transpires in classrooms.

From the training or behaviorist perspective, the good student might be characterized as a passive receiver of information working in close proximity to, but in isolation from, classmates. Time is spent memorizing material, filling in blanks in workbooks, and repeating the same kinds of practice problems. Students are expected to work quietly, neatly, and with a minimum of disruption. Often there is a great deal of importance placed on the correct answer and the orderly, sequential way in which it was obtained. Student performance is equated with supplying the correct answer in the correct way. Students are generally expected to work on the same task and require the same amount of time to accomplish it. "Schools typically treat children as if they were born with intellectual blueprints. They act as if the school's job were to lay down layer after layer of bricks, build walls, and fill up the mental rooms with facts" (Oakes & Lipton, 1990, p. 40).

Others believe that the current structure of teaching can be viewed as a product of the machine-age thinking of the industrial revolution dominated by reductionism, analysis, and mechanism (Romberg et al, 1990). Unknowns are dealt with by identifying their simplest parts and phenomena are explained by determining cause and effect relationships. Scientific management, a product of such thinking, emphasized the simplification of individual tasks, predetermined rules for task coordination, and detailed assessment. The pervasiveness of such thinking is seen in many school practices such as its organization by subject, topic and behavioral objectives; the content and structure of textbooks; and the roles of teachers and students. Both content and behavior have been organized into hierarchies for largely practical reasons.

In this new conception of teaching, the teacher is involved in a dialogue with students, a two-way interchange. This provides an opportunity to assess students' level of understanding and select authentic problems for solution. Teachers become active models, thinking aloud for students, exposing them to the process of getting an answer rather than just the product. They encourage multiple approaches by providing opportunities for students to share their strategies. Finally, they also provide support for students as they learn (Means & Knapp, 1991).

This new conception of the teacher interacts with a new view of the learner as a problem solver involved in creative and inventive ways in reducing the tension between what is known and new contradictory information. Children spend their time reading books, writing compositions, identifying dilemmas, and offering explanations to complex problems.

This new view focuses on integration of information and understanding and sees everything as part of a larger whole, with each part having interactive relationships with other parts. It does not reject training but seeks a thoughtful balance between education and training, between cooperation and individual effort, and between intuitive and analytical thinking. It stresses the integration of knowledge through its application to meaningful situations. Likewise, it promotes innovation through creativity and the creation of knowledge (Romberg et al, 1990, p. 29).

For example, in an approach called reciprocal teaching, the teacher first performs, models, and explains things to the student. Then the teacher relinquishes part of the task to the student as he or she seems capable of handling at the time. As the student becomes more competent, the teacher requires participation at a slightly more challenging level (Palincsar & Brown, 1989).

In other approaches summarization rules (Garner, 1987) and the specification of procedures (Reif, 1987) are used to provide support for learners while they are learning new complex skills. The rules and specifications seem to minimize the amount that the student must memorize or keep in mind when doing a particular task (Eylon & Linn, 1988).

In problem solving in various disciplines, students are provided extensive practice in solving problems in interactive situations such as having the instructor think aloud while solving problems or having students justify their answers to one another as they work together. An important feature of this approach to learning is that errors are seen as a natural part of the problem solving process (Resnick, 1987).

As a facilitator of learning the teacher is responsible for providing problems that draw on the strengths of students' prior experiences. For example, early home and community environments influence the language patterns of youngsters and thus their reactions to uses and structures encountered in school. By having the expectation that all students can learn, understanding the nature of students' out-of-school experiences, teachers can be better facilitators of learning (Heath, 1983).

4. Thinking skills need to be identified and taught. One of the early themes in the literature on teaching thinking is the notion that if we are to teach students to think, we need to identify specific skills of thinking, and then focus on how to teach those particular skills. However, there is not a consensus on just what those skills are. Various people are using different categorizations of skills as well as different approaches to their instruction.

In 1985 when Nickerson, Perkins and Smith did an extensive review of the teaching of thinking they found that four categories worked quite well to depict the types of thinking that people were attempting to teach: problem solving, creativity, metacognition and reasoning

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(Nickerson et al, 1985). These categories, although defined in a number of ways, generally can be characterized as follows.

Problem solving -- analyzing and resolving a difficult or perplexing situation (Marzano et al, 1988)

Creativity -- original and appropriate thinking usually leading to a product. Both originality and appropriateness are necessary conditions. A product that is perfectly fashioned but not original would not be considered creative nor would one that was original but does not fit the situation. (Nickerson et al, 1985)

Metacognition -- knowledge about knowledge and knowing. It includes "knowledge about the capabilities and limitations of human thought processes, about what human beings in general might be expected to know, and about the characteristics of specific people -- and especially oneself -- as knowing and thinking individuals" (Nickerson et al, 1985, p. 101).

Reasoning -- "to evaluate and generate arguments in accordance with the principles of deductive and inductive inference" (Nickerson et al, 1985, p. 111).

In 1988 when Marzano and his colleagues provided a framework for thinking under the auspices of the Association for Supervision and Curriculum Development, they used the following categories:

metacognition (including knowledge and control of self as well as knowledge and control of process),

critical and creative thinking,

thinking processes (including concept formation, principle formation, comprehension, problem solving and decision making), and

core thinking skills (including focusing, information-gathering, remembering, organizing, analyzing, generating, integrating and evaluating skills).

Suarez, Mills and Stewart (1987) look at psychological theories and attempt to present a more unified way of viewing thinking to derive some general principles that provide a greater understanding of psychological functions. They emphasize that every human being is capable of formulating thought and creating his/her own thought system. Because each person has a unique set of experiences and characteristics, each person has a unique thought system. They see it as crucial that each person come to understand his/her own functioning by understanding his/her thought system and that feelings and emotions are key indicators of a person's ability to reflect on his/her own thought system and understand and appreciate the thought systems of others.

By a thought system Suarez, Mills and Stewart (1987) mean the "bundle of associations stored in the brain" that constitutes "a sophisticated, interwoven network of thoughts" (p. 24). They emphasize the direct connection between personal beliefs and personal experience of life. "A thought system is a perceptual filter through which people screen and interpret all incoming data" (p. 25). They also note that a thought system will maintain its own internal consistency. If a new idea "is not compatible to the existing beliefs, that new idea will be attached or disregarded" (p. 27). Thus learning to think is a complex interplay of particular skills that help people perceive new information and experiences with the well established system of thought that a person has developed over time.

Presseisen (1988), Quellmalz, (1987), Ennis, (1987), Bransford, Sherwood and Sturdevant (1987) and others look at the area of thinking in slightly different ways, each having particular aspects that they prefer to emphasize. The field of teaching thinking is still evolving and various ways of categorizing and conceptualizing the field are expected to continue.

A key point, however, in all of these efforts is that some way of organizing and thinking about the skills that one is teaching is necessary. Educational goals about the nature of the thinking competencies to be learned need to be stated so that students, teachers and parents all are aware of what the schools are attempting to teach (Kuhn, 1990).

5. The teaching of thinking skills needs to be linked to content. A fundamental question that recurs when thinking skills curricula are discussed is whether thinking skills should be separated from or infused into the rest of the curriculum. It is possible to find experts in support of both positions and arguments which go both ways. The trend, however, seems to be toward a close link between content and thinking skills.

Separate programs have the advantage of

(1) being less likely to be overpowered by knowledge-based curriculum and thus lose their emphasis on the thinking skills,

(2) helping students gain clarity on the nature of thinking skills, and

(3) being more easily assessed across or outside of specific content areas. (Sternberg, 1987)

Separate programs, however, are more likely to disappear, may be shallow because they are separated from content and set up a false dichotomy between subjects and intellectual activity (Joyce, 1985). Furthermore, it sends the message that it is all right to teach the core subjects without requiring thinking because that will be done in the thinking class.

Infused programs

(1) do not require separate courses which may be hard to fit in the school's

schedule or priorities,

(2) seem to run less risk of never being applied outside the thinking-skills classroom, and

(3) reinforce the thinking skills throughout the curriculum, rather than conveying the message that thinking skills are something apart from other curriculum. (Sternberg, 1987)

Resnick (1987) lists the following advantages of a discipline-embedded approach:

(1) It provides a natural knowledge base and environment in which to practice and develop higher order thinking skills. According to current research, knowledge plays an important role in reasoning and thinking. "One cannot reason in the abstract; one must reason about something" (p. 36). The disciplines provide the materials to do this and they solve the problem of "empty thinking."

(2) It provides the criteria for what constitutes good thinking and reasoning within the disciplinary tradition. Each discipline has its own characteristic ways of reasoning. For example in the physical sciences, combinations of inductive and deductive reasoning methods are used, as well as mathematical tests and an extensive body of agreed upon fact.

(3) It insures that something worthwhile will have been learned even if transfer of higher order thinking skills is unattainable.

Rutherford and Ahlgren (1990) concur with Resnick, citing a list of activities teachers and students can do to encourage thinking as a component of science education. Key factors in effective science teaching and learning for true understanding include attending to activities and processes of science, problem solving, historical context, effective and clear oral and written communication, and the use of collaboration, inquiry methods, creative imagination, and skepticism. Science teaching and learning can and should provide a vehicle for encouraging thinking as well as be a source of discipline knowledge.

Many researchers suggest that we not treat the question of how to include thinking skills as an either/or matter (Nickerson, 1988-89; Sternberg, 1987). "On the one hand, it is important to treat the skills, strategies, attitudes, and other targeted aspects of thinking in such a way that students come to understand their independence from specific domains and their applicability to many; on the other, it seems equally important to demonstrate their application in meaningful contexts so students witness their genuine usefulness" (Nickerson, 1988-89, p. 34).

The proliferation of thinking programs can convey the false assumption that "thinking instruction is somehow contained in this abundance of programs and that offering one or more of them is sufficient" (Marzano et al, 1988, p. 5). Rather, there is the need to infuse teaching thinking in all curriculum areas.

Rather than dichotomize the issue it is more useful to recognize a difference in emphasis. Glaser (cited in Nickerson, 1988-89), for example, has emphasized the importance of domain knowledge. He does not deny the usefulness of general processes, but that they are not adequate by themselves and are best learned in the context of knowledge acquisition. Resnick's (1987) statement provides a useful summary.

> "A central issue, both for educational practice and for research that can guide that practice, is whether thinking and learning abilities are general -- that is, applicable in all domains of thinking -- or specific to a particular domain. The evidence shows clearly that thinking is driven by and supported by knowledge, in the form of both specific facts and organizing principles. This knowledge, together with the automated recognition and performance that come with extended practice, allows experts in any field to engage in more sophisticated thinking than people new to the field. At the same time, many aspects of thinking are shared across fields of expertise. These include a wide range of oral and written communication skills, mathematization and representational abilities, principles of reasoning, and skills of argument, construction and evaluation. These can be thought of as 'enabling skills' for learning and thinking. Generally speaking, people rely on powerful but only narrowly applicable thinking methods in domains in which they are expert and use broadly applicable but weak methods for learning and thinking in fields they know little about. Good thinkers need both the powerful but specific and the general but weak kinds of skills." (1987, pp. 45-46)

6. Knowledge is situation dependent. Closely related to the idea that thinking needs to be linked to content knowledge is the idea that knowledge must be linked to situations. Traditional instruction theory assumed that skills and knowledge could be broken into component parts and that they would function the same wherever they were used. Increasingly, cognitive theory is showing that knowledge must be embedded in some type of organizational structure and must be linked to situations and environments in which it is used. (Resnick, 1989).

7. It is inappropriate to treat thinking in a hierarchical learning sequence with a student needing to learn "basic skills" before learning "higher order skills." Another dilemma that plagues schools as they move toward an emphasis on teaching thinking is a well entrenched notion that learning is hierarchical. Although systems such as Bloom's (1956) Taxonomy of Educational Objectives have served educators in many ways, they have contributed to the misconception that students must master basic skills before they can attain or be instructed in higher order skills. "One consequence of adherence to this assumption for many students, particularly those deemed most at risk of school failure, is that instruction focuses on the so-called basics (such as phonetic decoding and arithmetic operations) to the exclusion of reasoning activities and reading for meaning" (Means & Knapp, 1991, p. 1).

The confounding of Bloom's lower order thinking skills (recall, comprehension and application) with basic content areas and the association of higher order skills (analysis, application, synthesis, and evaluation) with advanced content has conveyed the erroneous impression that basics can be effectively learned in the absence of thinking skills (Foster, 1989). Low achieving students are assigned to remedial curricula which focus narrowly on basic skills acquisition.

On the contrary, there is consistent evidence that young children and less proficient students can be taught the same strategies and processes used by more successful learners (Brown & Campione, 1990; Resnick et al, 1991).

> "Higher order thinking skills are often contrasted with basic skills, leading to the perception that such entities are not for all. Younger and more disadvantaged students are held accountable for basic skills, whereas higher order thinking skills are seen as part of upper school curricula or, worse still, optional extras. We argue that this is absurd; thinking and reasoning should be part of the curriculum from the earliest years, and indeed fostering effective reasoning should be the main responsibility of schools" (Brown & Campione, 1990, p. 109).

Component skills of problem solving should not be viewed as hierarchical because research on problem solving has revealed that each skill may be used repeatedly during various stages of the problem-solving process (Quellmalz, 1987). Furthermore, some "evaluative tasks are much easier than analytical tasks, and two analytical tasks may demand different approaches or skills, depending upon the scope and complexity of the problem or argument" (Quellmalz, 1987, p. 90).

8. Curriculum and assessment change when the emphasis is on the acquisition of thinking abilities. When the emphasis is on the acquisition of thinking abilities, the curriculum changes from one with an emphasis on teaching isolated knowledge and skills to one of helping students apply knowledge and focus in depth on a few problems and issues. There is also an emphasis on tasks that have meaning for the student so that learning becomes more internally motivated (Sizer, 1984; Means & Knapp, 1991; Oakes & Lipton, 1990).

Curricula should be focused on complex, meaningful problems; tasks should be global enough that their purposes are apparent to students; and the instruction of basic skills should be embedded in the more global tasks. A global task provides students with motivation, students have the opportunity to practice skills as part of a coherent performance, and the likelihood of transfer of the skills to real-world situations is increased. The tasks selected should make connections with students' out-of-school experiences and culture.

With such a change in emphasis, one rejects the idea that knowledge of mathematics can be transmitted from a teacher to a student. One would reject the characterization of student responses to questions as either right or wrong. Rather, student's answers make perfect sense-- to the student -- and these answers are one of the ways in which one can gain any understanding about the knowledge the student has constructed. A constructivist would reject a view of mathematics that does not include the active gathering of data, making and testing of conjectures, executing of mathematical procedures, and justification of results to oneself and others (Davis et al, 1990). Constructivism, therefore, is a conceptualization of mathematics as a discipline, and how learners in a mathematical community come to know mathematics.

In their monograph on curriculum reform in science, Shymansky and Kyle (1990) say that

> "The true manifestation of successful schooling is not how well students perform on in-school assessments. How citizens think, what they value, how analytical and critical they can be, how they question and reflect -- these are among the true measures of successful schooling." (p. 6)

Thus, if we desire citizens who are creative, reflective, critical thinkers and problem solvers, we must teach them "to think".

The traditional approach to curricula, which is still dominant in most schools, assumed students came to school with the same experiences, progressed at the same rate and learned in the same way. Built to standards of efficiency, lessons were simple, standardized, and easy to manage. The movement of the 60s and 70s was toward small, isolated behavioral objectives that stated what children will be able to do; this encouraged activities designed around those specific behaviors and separate testing of the objectives to see if they had been learned. This view of learning fit common notions of how to educate large numbers of children efficiently (Oakes & Lipton, 1990). The desire to efficiently cover the material in a time of mushrooming expansion of knowledge in most disciplines led to the curriculum emphasizing basic skills and facts. Consequently, the curriculum tended toward being repetitive, and decontextualized, and offering little integration of skills (Means & Knapp, 1991).

Since a separate literature review is being done on assessment through the OERI-funded research projects (Kane & Mitchell, 1992), the many assessment issues connected to curriculum reform will not be addressed in detail here. A few points are of particular importance, however, and will be mentioned briefly.

The move toward teaching all students to think has been closely linked to changes in student assessment. Because student assessment has become such a dominant feature of accountability systems during the past 20 or so years (Anderson, 1985), changing assessment is viewed as a key way to bring about change in curriculum and instruction in the classroom.

Teachers tend to pay particular attention to what is measured on tests; changing the content of tests, thus, is a key way to bring about change in the classroom.

Two fundamental assessment shifts of the past 20-30 years are closely linked to the shift to a greater emphasis on teaching all students to think. The first shift, which occurred largely in the late 60s and throughout the 70s, was the move from norm-referenced tests to criterion-referenced tests. Norm-referenced tests emphasize the performance of students compared to other students, usually of the same grade level. Criterion-referenced tests emphasize the performance of a student relative to some predetermined standard of mastery of the particular skill or knowledge being taught, irrespective of how well other students performed.

Norm-referenced tests have two characteristics that undermine the ability of many students to demonstrate their learning. First, complex sets of human capabilities are reduced to unitary traits. Students not performing well on such measures are easily labeled as lacking in intelligence or achievement (Wolf et al, 1991; Gould, 1981). Second, because the results of these measures emphasize the comparison of one student to another, they become tools for sorting and selecting students into groups, with lower performers often being placed in classes that focus on remediation of isolated skills rather than on higher level thinking. Intelligence may become characterized as rare and predictably located within groups by race, class, and gender (Wolf et al, 1991; Fass, 1989; Mehan et al, 1986).

Criterion-referenced tests were an attempt to move away from the emphasis on sorting and selecting and unitary definitions of intelligence or achievement to an emphasis on the particular skills and knowledge that a student was to master. Although this approach helped to move away from the idea that some students could not learn certain skills and knowledge, these tests did not help move away from treating knowledge and skills in isolated and small chunks. In fact, these tests are considered by many to have reinforced that idea.

Within the framework of norm-referenced or criterion-referenced testing, however, considerable attention was directed toward the measurement of specific skills labeled as higher order thinking skills, especially during the 70s and 80s. See Arter and Salmon (1987) for an annotated bibliography of thinking skills measures. The authors of the bibliography have classified the measures into six categories: (1) problem solving, (2) decision making, (3) inferences, (4) divergent thinking skills, (5) evaluative thinking skills and (6) philosophy and reasoning.

The seeds of a second major shift in assessment have existed for a long time. During the last 3 or 4 years, however, considerable national visibility has been given to this shift -- the move away <u>from</u> both norm-referenced and criterion-referenced tests that focus on isolated skills and knowledge <u>to</u> what is now being called performance or authentic assessments. This change is linked to the shift away from teaching isolated skills and knowledge toward learning that involves meaning-making and application of knowledge to real situations (Stiggins, 1991; Baker, 1990; Romberg et al, 1990, Wiggins, 1989; Anderson, 1987).

Although performance assessment or authentic assessment is defined in many ways, the basic idea is that students should be assessed while doing real life tasks. For example, if you want to know how well students write, have them actually write a meaningful story, article, or letter rather than having them make choices on a multiple-choice test about which sentence has the correct grammatical structure or which paragraph is organized in the best way. Production of something is a better measure of students' ability in an area than is recognition of certain features of a product created by someone else, especially when their response to those creations is reduced to a choice among four alternatives on a multiple choice test.

As performance assessments become more common, it is becoming clearer that they are measuring different aspects of learning than are traditional multiple-choice tests. The multiple choice tests may do quite a good job of measuring isolated skills and knowledge but performance assessments have more potential for measuring whether students can put skills and knowledge together to create a meaningful whole. Performance assessments also are being promoted as the basis for helping students reflect on their own learning processes. For example, portfolios -- one type of performance assessment -- may consist of a collection of papers that a student has written over time. The student may be asked to analyze the collection of papers to explain the progression of learning, both in terms of the ability to communicate through writing and the progression of learning about the content area (Anderson, 1992; Wolf et al, 1991; Wiggins, 1989).

9. Learning to think requires that many conditions within schools and the modes of instruction be changed. In the mideighties, the National Research Council convened a group of psychologists, educators, computer scientists, and philosophers to address the question of what American schools can do to more effectively teach what had come to be called "higher order skills." In her synthesis of the work of this group, Lauren Resnick (1987) captured the characteristics of the nature of thinking and learning that goes beyond the routine and rote. She described the key features of such thinking when it occurs

"— Higher order thinking is **nonalgorithmic**. That is, the path of action is not fully specified in advance.

— Higher order thinking tends to be **complex. The total path is not "visible" (mentally speaking) from any** single vantage point.

— Higher order thinking often yields **multiple solutions**, each with costs and benefits, rather than unique solutions.

— Higher order thinking involves **nuanced judgment** and interpretation.

— Higher order thinking involves the application of **multiple criteria**, which sometimes conflict with one another.

— Higher order thinking often involves **uncertainty**. Not everything that bears on the task at hand is known.

— Higher order thinking involves **self-regulation** of the thinking process. We do not recognize higher order thinking in an individual when someone else "calls the plays" at every step.

— Higher order thinking involves **imposing meaning**, finding structure in apparent disorder.

— Higher order thinking is **effortful**. There is considerable mental work involved in the kinds of elaborations and judgments required." (p. 3)

Thus, teaching students to think implies setting up conditions for learning where the path of action is not fully specified in advance, where multiple solutions, judgment and interpretation are expected, where conflicting multiple criteria must be used to derive a response to a situation, where uncertainty and self-regulation of the thinking process are expected, and where, with effort, the learner imposes meaning on apparent disorder and confusion of ideas and information.

This list of conditions versus the conditions in today's typical school are in sharp contrast. Within the traditional public school today, it is seen as good teaching to clearly specify the path for students to take, to expect one right answer, to have the teacher rather than the student regulate the rate and path of learning, and to address isolated skills and knowledge dissociated from meaningful activities (Goodlad, 1984; Sizer, 1984). For example, mathematics is largely algorithmic using standard examples with visible paths to single, unique solutions. Neither judgment nor interpretation are expected as problems are simplified to single criteria that are well defined in content with the information needed for solution being given. Regulation is external with meaning given or assumed (Romberg et al, 1990).

Others such as Sizer (1984) have recognized that a simple set of rules for instruction can not be set forth, but rather a new set of guiding principles or beliefs can be derived about the nature of teaching and learning, that need to characterize the school. Sizer developed nine principles that bring together notions about teaching, learning and the organization of the school in a way that schools can develop a new way of viewing how they operate. His principles are as follows.

<u>Intellectual focus.</u> The school should focus on helping students learn to use their minds well. It should not attempt to be "comprehensive" at the expense of it central intellectual purpose.

<u>Simple goals.</u> The school's goals should be simple: that each student master a limited number of essential skills and areas of knowledge.

Universal goals. The school's goals should apply to all students, although the means to the goals will vary as those students themselves vary. School practice should be tailored to meet the needs of every group of students.

Personalization. Teaching and learning should be personalized to the maximum extent feasible. To that end, a goal of no more than 80 students per teacher should be vigorously pursued, and decisions about curriculum, allocation of time, and choice of teaching materials and their presentation must rest unreservedly with the school's principal and staff.

Student-as-worker. The governing metaphor of the school should be student-as-worker, rather than the more traditional teacher-as-deliverer-of-instructional-services. A prominent pedagogy should be coaching, to provoke students to learn how to learn and thus how to teach themselves.

Diploma by "exhibition." The diploma should be awarded upon a successful final demonstration of mastery -- an exhibition -- of the central skills and knowledge of the school's program. The familiar progression through strict age grades and "credits earned" by "time spent" in class will be unnecessary.

Tone. The tone of the school should explicitly and self-consciously stress values of unanxious expectation ("I won't threaten you, but I expect much of you"), of trust (until abused), and of decency (fairness, generosity, and tolerance). Parents should be treated as collaborators.

Staff. The principal and teachers should see themselves as generalists first (teachers and scholars in general education) and specialists second (experts in one particular discipline). Staff should expect multiple obligations (teacher-counselor-manager) and commitment to the entire school.

Budget. Ultimate administrative and budget targets should include a total student load of 80 or fewer per teacher, substantial time for collective planning, competitive staff salaries and a per-pupil cost no more than 10 percent above that of traditional schools. Inevitably, this will require the phased reduction of some services provided in many comprehensive secondary schools.

These principles are to be debated within each school and community with faculties applying them in keeping with their particular students and conditions.

Although their work is not directed toward the school context but rather to thinking more generally, Suarez, Mills and Stewart (1987) argue that of critical importance to one's ability to change one's thought system is the environment in which thinking occurs. They say that people are able to step out of their own thought system when the conditions around them include

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characteristics such as appreciation, generosity, kindness, compassion, patience, understanding, insight, humor, self-esteem, cooperation, flexibility, and ability to concentrate.

However, conditions such as the following lock people into their current thought system: competition, need to prove self, confusion, commiseration, impatience, hurriedness, boredom, defensiveness, conflict, blame, self-righteousness, anger, and prejudice. Thus, new ideas and perspectives can not easily be incorporated into one's thought system when these conditions exist. Such a perspective is broader but consistent with Sizer's principle that the tone of the school should be one of unanxious expectations, trust, and decency. These perspectives have also been contrasted to the experience in schools where change is occurring (Anderson, 1991).

10. Changes are needed at administrative and policy levels as well as in the school and classroom if students are to learn to think well. As the national education reform efforts largely driven by political and business leaders outside of the schools converged with the new thinking about teaching and learning led by educators and educational researchers, there was growing recognition that the organizational structures of the larger education system (e.g., district and state policies and structures) have embedded within them contradictions to the new ways of teaching and learning. If students are to be more actively engaged in their own learning and are to be problem solvers, how can teachers teach these skills unless they are actively engaged in the life of the school and solving problems therein? The heavily hierarchical and bureaucratic structure of the education system is in contradiction to the type of teaching and learning necessary for students to learn to think (Anderson, 1989). The National Governors' Association and the Education Commission of the States both became active advocates during the late 80s of the idea that restructuring of the whole education system was necessary if students were to learn to think well. This orientation toward full system change resulted in a major national effort called Re:Learning initiated by ECS and the Coalition of Essential Schools (see later section).

11. An emphasis on helping students learn to create and shape their future rather than simply respond to it has opened more ideas about what constitutes the needed thinking abilities for all students as well as the modes of learning. As the emphasis on system change to support students' learning to think grows, more and more attention is being given to the connection with changes in the larger society and world. Not only must thinking, content, and situations be linked and congruent for change across teaching, learning, administration, and policy to occur, but these changes must be done in a way that helps students create and shape their future. Learning to think well needs to be focused on the life roles that students will eventually have -- citizen, producer, learner, family member, etc. -- and needs to help children recognize that they need to do more than respond to changes occurring around them; they also need to be developing a desired vision of their future such that they can help make it a reality (Banathy, 1991; Spady & Marshall, 1991). Skills of managing and shaping change, cooperating with others, and systems thinking and action are thought of as new, higher level ways of integrating content and thinking. Thus, the type of skills to be taught related to thinking need to keep evolving as the future unfolds.

Constructivist Learning and Teaching

The sweeping changes that are being recommended by the mathematics and science education communities, as well as by thinking skills advocates, are based on psychological, philosophical, and pedagogical positions -- supported by a growing body of research -- which posit that learners actively construct their own understanding of the world around them by wrestling to fit their perceptions of that world into their existing web of knowledge and understanding. These positions, often collectively termed "constructivism," have been articulated in various ways by several writers (Cobb et al, 1992; Confrey, 1990a; Noddings, 1990; Shapiro, 1989; von Glaserfeld, 1987). These theorists disagree about some of the particulars, but generally agree, as Davis and his colleagues (1990) state, that

> "... learners have to construct their own knowledge -- individually and collectively. Each learner has a tool kit of conceptions and skills with which he or she must construct knowledge to solve problems presented by the environment. The role of the community -- other learners and the teacher -- is to provide the setting, pose the challenges, and offer the support that will encourage mathematical [or scientific] construction." (p. 3)

The following items elaborate this perspective on learning and teaching in the school context.

1. Learning is dependent upon the prior conceptions that the learner brings to the experience. Individual learners bring unique networks of prior knowledge structures, beliefs, and attitudes to bear on each situation they encounter. These prior conceptions serve as the foundation for the acquisition and integration of new knowledge.

> "It has been demonstrated in numerous studies that learners more readily acquire new knowledge when they are able to relate new ideas to already existing ideas or to language which they already possess." (Shapiro, 1989, p. 714)

Learning is not "a simple process of accretion but involves progressive consideration of alternative perspectives and resolution of anomalies" (Confrey, 1990, p. 32).

In contrast to the constructivist understanding of learning, educational practice in America has been dominated by approaches in which the teacher's task consists of providing a set of stimuli and reinforcements for the purpose of getting students to emit a certain response (Yager, 1991). The first step in many traditional science classes, for example, is memorizing vocabulary. Students learn by memorizing definitions of concepts or algorithms to solve problems, but often fail to understand the regularities in events, objects, or relationships designated by the concept labels or formulas. They do not acquire the meaning of concepts.

"Knowledge cannot be transferred by words without first an agreement about meaning and some experiential base. Explaining a problem will not lead to understanding unless the learning has an internal scheme that maps onto what a person is hearing. Learning is the product of self-organization and reorganization. Knowledge is not acquired passively." (Pines & West, 1986, p. 597)

2. The learner must construct his or her own meaning. As indicated in the above quotation from Pines & West, learning is not the result of simply taking in knowledge in a form designed by someone else. Students must organize and reorganize knowledge themselves. It is not a matter of passively taking in information and adding it to the storehouse of what the student already knows. It is an active process of working with this new knowledge until it "fits" with prior conceptions and has meaning within this learner's overall system of understandings. Memorizing is not the essence of learning.

While the general notion that learners must construct their own meaning has been espoused by some philosophers for centuries, the emerging perspectives from relatively recent cognitive research reported in the literature (e.g., Confrey, 1990; Pines & West, 1986) add to this general notion new richness and far greater understanding of just what this process entails.

3. Learning is contextual. The meaning that new knowledge has is highly dependent upon its context. Knowledge has different meanings in different contexts. It has little meaning independent of any context. School science and mathematics knowledge often has little meaning for students because it is presented in the abstract, independent of any meaningful context. Concrete experiences such as those acquired in laboratory activities can provide some of this context. The overall framework of the discipline being studied and its major themes are another aspect of context.

This understanding of learning can have many implications, depending upon other perspectives one may hold about a variety of matters. For example, some proponents of more applications of science knowledge in the curriculum -- whether practical applications of the knowledge or the study of science-related societal issues -- argue for their position partially on the basis of the increased understanding learners have of basic science concepts when they are studied in the context of applications, in addition to the context of the structure of the discipline itself.

4. Learning is dependent upon the shared understandings that learners negotiate with others. When learning in school, students and their teachers bring individually held knowledge, beliefs, and feelings to the classroom. Through their daily interaction, teachers and students negotiate shared understandings of knowledge (Brown et al, in press; Tobin, 1990; von Glaserfeld, 1987, 1989, 1992). These intersubjective meanings are often referred to as "consensual domains" (Richards, 1991).

Increasing recognition of the importance of this shared meaning has led to greater attention to the nature and organization of classroom learning experiences. Given this understanding of learning, such classroom activities as discussion and cooperative learning are seen in a new light.

5. Constructivist teaching involves understanding students' existing cognitive structures and providing appropriate learning activities to assist them. One's understanding of learning obviously has major implications for how one teaches. While constructivist teaching probably is not as well understood as the learning ideas on which it is based, it is clear that teachers need to attend to students' existing cognitive structures and provide learning activities accordingly.

Several approaches to developing an understanding of students' cognitive structures are prominent in the research literature. Meaningful learning, domain-specific restructuring, misconceptions, and novice-expert shifts are some of the ways in which various researchers have conceived of constructivist learning (Novak, 1991, 1988, 1984 & 1977;Wandersee, 1990 & 1987; Vosniadou & Brewer, 1987; Carey, 1986; Novak & Gowin, 1984).

Meaningful learning is predicated on a hierarchical structure of students' preconceptual knowledge. Learning processes are designed to assist students

> "to understand the role concepts play in making sense out of experience, the nature of cultural evolution of concepts and the psychological nature of concept learning and concept use in problem solving." (Novak, 1977, p. 474)

Domain specific restructuring begins with an identification of misconceptions. Learning is based upon the creation of a novice-expert shift in the organization and use of knowledge. A parallel can be drawn between such a novice-expert shift and the historical development of science theories. Just as historically, successive conceptual systems can differ in the domain of phenomenon for which they account, the type of explanations acceptable within the system, and the individual concepts at the core of the system, so too does the development of student conceptions evolve. This development of understanding results in a lack of equivalency among terms, a lack of translatability among concepts, and a miscommunication among communicants. Similarly, teachers and students, apparently using the same terminology, can miscommunicate about the system under study, the theories that govern its application, and the conditions under which it operates (Carey, 1986).

A constructivist view of learning seems to conflict with the teaching methods and the science curricula observed in most of our nation's classrooms.

> "...the science curricula of schools and colleges represent and present public knowledge -- other people's knowledge -- imposed with the power of authority on the students, who come with a wealth of beliefs about the world and the way it

works -- their own private understanding -- which often conflict with what is taught and what is to be learned." (Pines & West, 1986, p. 597)

But rote learning is often used because it is easier. Students come to the learning situation with preconceptions or misconceptions that interfere with real learning. It is easier to just memorize facts because it does not build on prior learning and, therefore, is not influenced by misconceptions. Students when exposed to rote learning for several years come not only to accept it but to actually prefer it. Learners must be made aware that meaning is something they construct, not something given them by the teacher.

6. Teaching can utilize one or more of several key strategies to facilitate conceptual change depending upon the congruence of the concepts with student understanding and conceptualization. A number of models for conceptual change have been proposed which recognize three major strategies in the conceptual change process (Prawat, 1989; Pines & West, 1986; Osborne & Wittrock, 1985). In each model some variation of awareness, disequilibrium, and reformation occur. Awareness is based upon conscious or unconscious sensory input selection and attention to information sources, such as activities and experiments, followed by the generation of links between the learner's prior knowledge and this new sensory input. From these input sources and link development, meanings are constructed.

Once meaning has been constructed, the disequilibrium phase consists of evaluation of constructions for consistency or dissonance with existing structures (Osborne and Wittrock, 1985). This is accomplished in many ways. Anomalies or "discrepant events" that challenge existing belief systems can be introduced to stimulate student discussion and to generate new perceptions (Pines & West, 1986; Nussbaum & Novak, 1976). The main focus of the disequilibrium phase is to force students to examine their conceptions and reflect upon the compatibility between their conceptions and their experiences.

To reformulate their thinking, during the reformation phase, students may be presented with formal concepts that lead to the resolution of anomalies and to the dissipation of cognitive dissonance.

> "Supposedly, the students will be so uncomfortable with the cognitive dissonance brought about by the discrepancies between their existing belief systems and the anomalous events observed that they will eagerly accept the formal theories being offered as their own." (Pines & West, 1986, p. 596)

For Osborne and Wittrock (1985), this reformation may occur with or without significant changes in the existing knowledge structures. Giving up an existing knowledge structure can be threatening; consequently, some students will develop a second parallel structure. This does little to help students develop a unified, coherent view of science. For successful subsumption or reformation, students need to be encouraged to generate firm links between their constructed meanings and a variety of appropriate memory knowledge structures.

Motivation critically influences the entire process. "Students need to understand that effort is required to construct meanings and to successfully embed new ideas in memory, and need to feel that the effort involved in the process is worthwhile" (Osborne & Wittrock, 1985, p. 75). Prawat (1989) suggests that motivation, in form of disposition for retrieval, is just as greatly influenced by the organization and reflective awareness placed on the disposition by the student as is the access of knowledge and strategy.

7. **The key elements of conceptual change can be addressed by specific teaching methods.** Awareness of information through sensory input selection and attention focuses on experience and clarification activities "in which the teacher provides a range of activities, followed by class discussion, designed to elicit and highlight the existence and nature of competing points of view" (Pines & West, 1986, p. 595). Awareness can be stimulated further by the use of focus questions, carefully worded headings and subheadings in printed materials, substantive objectives to clarify the lesson, and instructions closely focused on the key purpose and design features of experiments (Osborne & Wittrock, 1985).

Also tied to the awareness phase is the generation of links between the learner's prior knowledge and the new sensory input. To assist this process teachers can provide reminders of important, relevant aspects of previous and present lessons, examples relevant to the learner's prior experiences both in and out of the classroom, multiple explanations in various forms addressing all or most of the senses, and multiple exemplars and nonexemplars of the concepts and definitions (Osborne & Wittrock, 1985).

Socratic dialogues facilitate the awareness of discrepancies, which is necessary in the process of abandoning old beliefs and the acceptance of a fundamentally different conceptual structure. Socratic dialogue functions like anomalies in the paradigm shift of revolutionary science. As a teaching method, it involves an active understanding of the student's point of view, the proposition of alternative frameworks, the creation of conceptual conflict, and the assistance for students with the students' conceptual construction of consistent theories (Vosniadou & Brewer, 1987).

Because constructions may be accepted without evaluation, assuming that the constructed meaning is the intended meaning or insufficiently evaluated to detect inadequacies, "teachers need to make available a range of models, experience, demonstrations, worked examples and analogies to enable pupils to test out their constructions" (Osborne & Wittrock, 1985, p. 73). The use of analogies and metaphors can facilitate spontaneous restructuring of new schema as well as the explicit teaching of a new structure. Physical models can induce the construction of a new schema by internalizing the physical model (Vosniadou & Brewer, 1987). To further accentuate discrepancies, Posner, Strike, Hewson and Gertzog (1982) imply that the teacher needs to play "devils advocate," presenting opposing view and stimulating student discussion.

In the reformation phase, the presentation of formal concepts leads to the resolution of anomalies and to the dissipation of cognitive dissonance (Pines & West, 1986). To support the motivational requirement necessary to facilitate student reconceptualization process, Osborne and Wittrock (1985) propose that teachers

(1) provide opportunities for the consideration, contemplation, and expansion of the students' view of the world and the development of their language to facilitate their description and explanation of their views;

(2) provide encouragement for, challenges to and reflections of students' views to improve student understanding of these views; and

(3) engender an understanding in students that making sense of experience and generating meaning is dependent upon the individual student's action.

Thus, the implications of the constructivist model for teaching are that teachers need to provide students with opportunities to have new experiences, to ask questions about the experiences of themselves and others; to select and attend to the sensory input from these experiences in useful ways; to construct ideas related to the experience, in part and in its entirety, to be challenged on their constructions; and to test the practicality of their constructions (Osborne & Wittrock, 1985).

8. Constructivism leads to new conceptions of what constitutes excellence in teaching and learning and in the roles of both teachers and students. Learning takes place in a social context. The implications for what occurs in classrooms is profound. The classroom will no longer be teacher-centered with the teacher being "the font of all knowledge." The teacher, under this new regime, will serve as a director or pathfinder guiding student learning, clarifying information when necessary, and maintaining an appropriate environment for learning. The student must now shift from that of a passive receptacle to that of an active participant, exploring, investigating, discussing, and constructing his/her own knowledge. These new conceptions lead to new roles for teachers and students. Such role changes are among the most difficult changes to attain.

<u>Teachers</u>

In both mathematics and science teaching, changing the role of a teacher from teacher-disseminator in a transmission model of teaching and learning to that of teacher-facilitator in a constructivist model of teaching and learning hits at the very heart of a teacher's belief system. A belief system change requires new views of one's self in three areas: one's occupational identity, one's sense of competency, and one's self-concept (Fullan & Stiegelbauer, 1991).

Fundamental to all three of these components of change is how a teacher views him/herself as a professional. A teacher's professional self-view develops in his/ her initial training but undergoes continuing modification as a result of professional experience, professional development activities and personal growth (Spector, 1989).

Professional views. There are several possible views a science teacher can adopt in relation to his or her profession that generally originate in initial training. One view is that of a discipline-trained scientist. In this view the science teacher is a biologist, earth scientist, chemist, or physicist, who is also trained as a teacher or educator.

Another professional view is that of educator or teacher who is most conversant with the theory and practice of education, and secondarily with the body of science knowledge. He or she often has a relatively strong background in one of the sciences (often an undergraduate major) and in addition a peripheral knowledge in one or more additional science disciplines. In other cases this science background is more multidisciplinary. In either case, the teacher having this orientation tends to approach the subject matter through his or her knowledge of educational theory. This person is generally speaking the biology teacher, the earth science teacher, the chemistry teacher, or the physics teacher.

These professional perspectives represent different occupational identities. This sense of identity influences how a teacher views his or her professional role as a teacher, the role of students and how curricular change occurs (Fullan & Stiegelbauer, 1991; Spector, 1989). Using teachers at all grade levels and many areas of expertise, Zahorik (1991) found that teaching style is related to teacher ideology. Tobin's (1990) grounded theory of teaching associates beliefs about teaching and learning with teaching roles; his research shows such roles to be malleable.

Science teachers' sense of professional identity also is influenced by their degree of commitment to preparing their students for various postsecondary school occupational or educational options. Chemistry teachers piloting an applications-based chemistry curriculum were noticeably worried that college-bound students would not have sufficient preparation to take college level chemistry if this less mathematical course were the students' only chemistry background (Anderson, 1987). This concern was prominent despite little evidence that college professors expect chemistry mastery on the part of entering students (Yager & Penick, 1987), or that having taken high school science will improve college science grades (Craney & Armstrong, 1989; Yager & Krajcik, 1989; Yager et al, 1988).

Sense of competence. Science teachers of disciplines taught at the upper high school levels often depend on former students' anecdotal reports of success to rate their teaching competence. This personal competence is measured by teachers' personal perceptions of how well potential science majors were prepared for college level science classes (Tobin et al, 1988; Anderson, 1987). Similarly, science teachers at lower high school levels tend to assess their

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personal competence on the basis of their perceptions of their students' preparation for upper level college preparatory high school classes. In a reform movement attending to education for all, science teachers' sense of professional competence will need to be based on feedback pertaining to the success of all of their students, not just those going on to more advanced study of science. The greater the teacher's awareness of his/her beliefs about teaching and learning, the better the match between the teacher's teaching and the students' learning and the greater the teacher's sense of competency (Tobin & Fraser, 1990).

Self-concept. Self-concept is a third factor that may need to change to accommodate real curricular change. This self-concept can hark back to the issue of occupational identity. Some areas of science, for example, appear to be held in greater or lesser regard, often based on the rigor of the discipline and the mathematical requirements to succeed in the discipline. A perceived, but persistent, hierarchy of science disciplines and, therefore, science teachers exists. Physics teachers are viewed at the pinnacle, with chemists a close second, and teachers of biology at a lower rung. Earth science staff members have a more nebulous location due to the numerous individual disciplines they represent and whether or not they are part of the middle/junior high school staff or the high school staff.

An awareness of this hierarchy is prevalent not only among science teachers but among the entire secondary school staff and students (Tobin et al, 1988). It has implications for curricular reform endeavors where an attempt is made to integrate science content in courses that cut across the several science disciplines and where more attention is given to the applications of science to societal issues, an area often perceived by teachers to belong to the social studies curriculum.

When defining the attributes of an exemplary science teacher, Tobin and his colleagues (Tobin & Fraser, 1990; Garnett & Tobin, 1988) emphasized that effective practice derives from two interactive sources, beliefs about teaching and learning, and a reservoir of discipline-specific pedagogical knowledge. Exemplary teachers draw upon these two resources to maintain a learning environment conducive to student learning, to encourage active student participation, and to monitor student understanding of content needed to attain high level cognitive outcomes. Both these teacher attributes have their beginnings in one's occupational identity through preservice and inservice training, and they impact competency and self-concept through the way this expertise plays out in the classroom. In fact, in one case study the greatest impediments to change were poor science content, which led to poor pedagogical content knowledge and irreconcilable teacher beliefs about teaching and learning (Tobin & Espinet, 1989).

For curriculum change to occur, it is necessary to influence all three of these factors -- occupational identity, one's sense of competency, and self-concept. Tobin and Fraser (1990) believe that by first identifying and then modifying the metaphor(s) that describe teacher beliefs about teaching and learning, a teacher can become effective in improving student learning of high level cognitive science outcomes. Spector (1989) sees the change more as part of a naturally occurring growth toward self-actualization as a teacher that is closely aligned with the physical and psychological climate and teacher norms of the school in which the teacher functions. Spector's view is consistent with Fullan and Stiegelbauer's (1991) review of the teacher change literature.

Students

The role change from "student-knowledge acceptor" in a transmission model of learning to that of "student-knowledge constructor" in the constructivist model of learning requires that students take an active role. Until recently, student concerns about change have rarely been considered as a part of the change process, because of their passive role in the system (Fullan & Stiegelbauer, 1991). With their new active role, a new area of research is opening up. From the scant work that has been done, it can be inferred that students experience such changes in any of several ways -- with indifference or confusion, with relief resulting from a temporary escape from boredom, or with a heightened interest in learning (Fullan & Stiegelbauer, 1991).

Students are confused by change when the change and change process are unclear in the minds of the staff initiating the change. Indifference results when students are consciously or unconsciously excluded from the change process. Students may be excluded unconsciously due to a lack of recognition of the students' need for involvement; the result is a reaffirmation of their isolation in the education system. Conscious exclusion may result from not viewing the learner as having responsibility for his/her learning.

While student expectations of change generally have been neglected in the past, it is now recognized that without student participation, innovations requiring new roles on the part of the students will fail if students reject the new roles. Students have been found to participate to the extent that they understand and are motivated to try what is expected (Fullan & Stiegelbauer, 1991). Students' past experiences involving change may not have been conducive to increasing their understanding and motivation and can create a barrier to change.

Classroom implementation of constructivist teaching will require classroom level pedagogical and content changes. Many of these changes will fly in the face of parental school experiences. Without a rationale for the changes, students are frequently caught in a crossfire between parents and teachers, adding to student rejection of the change at the worst, or to student confusion at the least. Students need to be enfranchised by a reform that requires them to take a new, more active role in their own learning. As with teacher inservice education, student enculturation may need to be an active part of an implementation program in schools where the present school culture does not encourage student involvement in either learning or change processes.

9. In constructivist teaching and learning, more emphasis is placed on learning-how-to-learn than on an accumulation of facts, creating a philosophy of content in which "LESS IS MORE." As the field of science, for example, continues to generate more and more knowledge, it is increasingly apparent that it is impossible for students learn this vast collection of information. With this rapid pace of change, facts often become obsolete. Even though there is much information that students need, a focus on increasing this amount of information is counterproductive. It is most important to give students an understanding of how science works and an ability to read and analyze scientific information. Specifically, concepts and skills need to be prioritized so the most important ones are emphasized. As with mathematics reform, students need to develop quality understanding rather than only receive a quantity of information.

One idea of how best to help students develop an understanding of how science works, why it asks the questions it does, and why it uses the methods it does is the adoption of newer views about the nature of science (Duschl, 1985). These views derived from the works of Kuhn, Lakatos, Laudan, Giere, and others provide a more conceptual understanding of how science operates in the day-to-day practical, political, and sociological world of the scientist (Duschl & Gitomer, 1991; Loving, 1991; Duschl, 1989 & 1988).

"Less is more" is a central theme of Project 2061 and has had a profound influence on the proposed curriculum of NSTA's SS&C (Aldridge, 1991; Rutherford and Ahlgren, 1990). As Songer and Linn (1991) assert in their work with middle school students in thermodynamics, there is a "danger of focusing science instruction too narrowly on facts or isolated pieces of scientific knowledge. Students rarely spontaneously integrate information presented in isolation" (p. 781). Instead, instruction needs to assist and support students in constructing an integrated understanding of science which is more predictive and productive than knowledge of isolated ideas.

In their review of learning and instruction research, Eylon and Linn (1988) summarize the findings of concept-learning research, especially as it pertains to integrating in-depth coverage of science topics. This approach can assist students in achieving a coherent understanding of science. Specifically, in-depth coverage can "elaborate incomplete ideas, provide enough cues to encourage selection of a different view of a phenomenon, or establish a well-understood alternative" (Eylon & Linn, 1988, p. 263), and promote the development of problem solving skills, all of which are major concerns with a concept learning perspective of instruction. Further, they suggest that from a combined concept-learning, developmental, differential, and problem solving perspective,

> "the cognitive need for systematic 'in-depth' coverage of a few science topics is at odds with the conventional 'in-breadth' coverage of many science topics. One way to resolve this conflict is to explicitly choose a few central and important

concepts for systematic coverage, while dealing with the relatively unimportant concepts in less detail." (Eylon & Linn, 1988, p. 290)

The issues raised in this section, and the information about learning and teaching, have been discussed here in a fairly general manner. In the upcoming sections, attention will be turned specifically to these matters in the context of the specific mathematics, science, and thinking involved.

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MATHEMATICS EDUCATION IN THE SCHOOLS: THE STATE OF THE DEBATE

Introduction

Teachers, administrators, parents, policymakers, and taxpayers are all involved in debates about the best ways to improve teaching and learning in school. The debate about the changes that need to be made in the teaching of school mathematics has moved beyond that which is occurring among science educators or among advocates of critical thinking across the disciplines. Several forces have pushed the debate in mathematics to another level. The first force at work is the sheer weight of evidence that shows that most students are not leaving school with much understanding of, or appreciation for, mathematics, a subject that is seen by all of the groups cited above as crucial for both informed citizenry and economic competitiveness.

The second force that has pushed the debate forward is a reconceptualization, among such diverse groups as mathematicians, mathematics educators, cognitive psychologists, and cultural anthropologists, about what mathematics is, what it means to know mathematics, and just how one comes to know mathematics. The new view of mathematics as a culturally constructed way of looking at the world, an experimental science in which practitioners model real-world phenomena and search for patterns in numbers, shapes, and symbols, is quite different from more traditional views of the subject. This new view suggests that merely focusing on the elegant, efficient, logically connected end-results of this search is not appropriate for school instruction. Rather, students ought to engage in the very processes mathematicians engage in in order to actively participate in the culture of mathematics. If the growth of mathematical understanding involves both the active sense-making of individuals and the collective negotiation of shared meaning in mathematical communities, then profound changes are needed in the ways in which mathematics is taught in schools.

The third force at work is a small but growing body of research evidence that suggests that if instruction in regular classrooms and by regular teachers is designed with this reconceptualization of mathematics and mathematics learning in mind, then student understanding of what mathematics is, what it means to know mathematics, and how to go about learning mathematics would be improved.

Mathematics education is addressed here in four sections. In the first, several pieces of evidence that underscore the need to change modal forms of mathematics instruction in the schools are recounted. These findings have been chosen as much for what they suggest about what might be done differently as for what they say is wrong. The second section outlines a vision of how mathematics teaching and learning might look if one adopted the reconceptualization outlined above. Several documents, produced by national groups of mathematicians and mathematics educators, outline such a vision to a degree of specificity not currently available to science educators or proponents of critical thinking across the disciplines. The third section of this review describes preliminary results from several research studies which have attempted to change both the "what" and the "how" of mathematics teaching in regular classrooms at different grade levels. While the specific theoretical and conceptual bases, research designs and content domains differ, there are several common themes that run through the studies we highlight. The final section lists several current research and development projects designed to improve mathematics teaching and learning in the schools.

Why Change Mathematics Teaching?

Does What We Are Doing Work?

The short answer to this question is that current practice simply does not result, on average, in high-quality mathematics learning in schools. In this section, we recount some of the evidence that supports this assertion.

The Second International Mathematics Study (SIMS) examined in detail the mathematics taught to and learned by 8th and 12th-grade students in 20 countries during the 1981-82 school year. The study (McKnight et al, 1987) investigated the intended mathematics curriculum, the actual curriculum and how it was taught, student achievement and student attitudes from an international perspective. American students at both grade levels were found to perform, on average, near the bottom of the list on the measures used. In addition, the top American students performed at levels that were comparable to the average students in the highest scoring countries.

The National Assessment of Educational Progress (NAEP) is a congressionally mandated, on-going study whose purpose is to report the status and trends in educational achievement in the United States. Approximately 150,000 9-, 13-, and 17-year-olds provide the nationally representative sample for this study, which is conducted every 4 years.

Data on mathematics achievement from a report on the 1986 NAEP document the failure of large numbers of mathematics students in the United States to solve problems of modest complexity, even when they possess the computational skills necessary to do so (Dossey et al, 1988). For example, among 17-year-olds, 96 percent demonstrated proficiency with the basic operations of arithmetic, but only 6 percent "displayed abilities in multi-step problem solving and algebra" (Dossey et al, 1988, p. 49).

The International Assessment of Educational Progress (IAEP) was conducted in 1988 by the Educational Testing Service. The study used items from the 1986 NAEP to compare 13-year-old students from the United States with those from South Korea, Spain, Ireland, United Kingdom, and four Canadian provinces, using an overall measure of mathematics achievement similar to that used in the NAEP studies. Researchers reported that American students scored, on average, at the bottom of this list (cited in Robitaille and Travers, 1992). While 40 percent of South Korean 13-year-olds reached proficiency in geometry, measurement, and multistep problem solving, only 10 percent of American students did so.

Three of every four Americans stop studying mathematics before completing career or job prerequisites. Most students leave school without sufficient preparation in mathematics to cope with either on-the-job demands for problem-solving or college expectations for mathematical literacy (Mathematical Sciences Education Board, 1989). The large-scale national and international studies cited above provide empirical evidence of the inadequate results of mathematics education in the United States. Though not alone, the work of Alan Schoenfeld in particular underscores the need for fundamental changes in the classroom instruction that influences these results.

In a year-long study of a high-school geometry class, Schoenfeld (1988) documented the misconceptions about geometry that resulted from "good" teaching. Even though this class was efficiently run, there was mutual respect between teacher and students, and students did well on the performance measures that counted in that school, they nonetheless developed the beliefs that form was more important than substance, that if problems could be solved it could be done in a few minutes, and that mathematics is a subject that consists of facts derived by others that are inaccessible to them except by memorizing.

Schoenfeld's own teaching experience (Schoenfeld, 1985) has confirmed for him that many students learn that mathematics is a disconnected set of rules, produced by others, that must be memorized so that correct answers to irrelevant exercises can be obtained. They have learned to take a passive role in learning information over which they have no control. For example, in his work with college students who had extensive mathematics experience and enjoyed the subject, he observed students who had difficulty solving a geometric construction problem, having just proved the theorems that provided the information they needed.

This lack of connection between procedure and understanding is a common finding at other grade levels as well. Younger students, for example, often solve word problems in arithmetic by circling the numbers and, beginning from the end of the problem, search for the "key word" that will tell them what operation to perform (Schoenfeld, 1985). Thus, though they may be able successfully to apply the appropriate mathematical operation to a problem and correctly calculate an answer, their success is simply a reflection of their ability to employ the right procedure at the right time.

What Are the Implications for Instruction?

The results of these studies are discouraging; however, by identifying several common features of American mathematics classrooms and the schools in which they operate, these studies provide some hints about how these classrooms might be changed. For example, survey data collected as part of the NAEP study indicate that "instruction in mathematics classes is characterized by teachers explaining material, working problems at the board, and having students work mathematics problems on their own -- a characterization that has not changed across the eight-year period from 1978 to 1986" (Dossey et al, 1988, p. 76). Schoenfeld's work suggests that this ubiquitous pattern of instruction in mathematics classes is, at least in part, responsible for the poor results cited above.

A second feature of American mathematics classrooms and schools is differential course-taking, ability grouping, and tracking. This feature has been identified by each of the large-scale studies cited above as an important factor that distinguishes between the mathematics experiences of American students and those of students in other countries, as well as between the mathematics experiences of different groups of American students.

Data from the SIMS study relate the poor showing of American eighth- and twelfth-graders to a curriculum that inequitably distributes opportunities to learn. The researchers identified four distinct curriculum tracks in force in most schools in the United States by grade eight: Remedial, Typical, Enriched, and Algebra. Each of these levels was markedly different from the others regarding the emphasis given to various content strata, such as arithmetic, measurement, geometry, algebra, and statistics. Upper tracks were characterized by decreased emphasis on arithmetic and increased emphasis on algebra. However, even the highest track was deprived; almost no geometry was covered in this course, typically a clone of ninth-grade algebra (McKnight et al, 1987).

Data from the NAEP study (Dossey et al, 1988) support the relationship between academic course-taking and mathematics proficiency. They also point to a strong relationship between school program and academic course-taking (and, therefore, with proficiency). In 1986, 52 percent of students reported being enrolled in an academic or college-prep program, 38 percent in a general program and 10 percent in a vocational/technical program. Among academic track 17-year-olds, 61 percent reported having completed second-year algebra while only 28 percent of general track, and 18 percent of vocational track students reported doing so. Large differences in proficiency level coincided with these differences in course-taking.

Conclusions about the detrimental effects on all but perhaps the highest-achieving students of sorting students into groups by ability are supported by a large body of research. (See, e.g., Oakes, 1985 & 1988; Gamoran & Berends, 1987.) The authors of the SIMS study conclude that:

> "The practice of early sorting of students into curricular tracks that lead to vastly different opportunities to learn high school mathematics must be carefully re-examined. Currently, significant proportions of young students are being assigned to mathematics classes that offer relatively little opportunity to learn the mathematics content needed for success in high school and beyond" (McKnight et al, 1987, p. 113).

To summarize, there is a preponderance of evidence that indicates that most students are not benefitting from their mathematics instruction in school; current practices simply do not work for large groups of students. These results also hint at some of the practices that should be changed. In the next section we will outline the response to the current situation that has been proposed from within the mathematics education community.

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How Would Change Look?

For some what follows might seem like yet another mathematics reform bandwagon. Historically, proposals for changing the way mathematics is taught have been based on changes in the field of mathematics or in psychology (Kilpatrick, 1992). One recent and painful example of such a reform bandwagon is the "New Math" movement, which began in response to concern about mathematics education from the academic mathematics community (Kilpatrick, 1992; Hayden & Rudolph, 1984). The phrase "New Math" refers to the collection of mathematics curriculum revisions of the late 1950s to early 1970s that utilized the precise language and formal proofs common to mathematicians and emphasized the abstract structures of the discipline (Hart, 1985). It was a top-down approach to change that introduced many cosmetic changes to the K-12 curriculum, but the substance and goals of the old curriculum were changed very little (Kansky, 1985; Sarason, 1971). Drill and practice remained, for example, but took the form of every child being required to prove that $(a)(0) = 0$ for all elements a in the set of real numbers **R** (Hart, 1985).

A number of characteristics of the current reform movement differentiate it from both the "New Math" and the "Back To Basics" reaction to it. The current reform efforts enjoy a much more broad and comprehensive base of support, as evidenced by the participation of education researchers, curriculum specialists, academics from other fields, and practitioners, in addition to mathematicians. These efforts are based on a fundamentally different view of mathematics and mathematics education. While these efforts include revision of texts, they go much further; while they require retraining of teachers, unlike the "New Math" they recognize this essential component at the outset.

The mathematics education community has contributed to the continuing debate about how to improve the learning of mathematics in schools by stating a very specific and ambitious vision for changing school mathematics and its teaching. Several documents have been published by the National Council of Teachers of Mathematics (NCTM) and the Mathematical Association of America (MAA). They represent the collaboration, over many years, of mathematicians, educators, policymakers, and teachers; they outline changes in both the curriculum taught in the schools, and the ways in which that curriculum is taught and learned. After a brief outline of the most important assumption underlying these documents, we will outline their major points.

The Underlying Assumption: Constructivism

While the constructivist orientation seems well suited to mathematics reform, it is not without controversy. As Schoenfeld (1992a) notes, a commitment to the notion that mental structures exist and influence what one learns "comes cheap" (p. 290). So-called "radical constructivists" go further; they assert that there are only intersubjective meanings for the experiences that individuals share. Rather than struggling to make sense of some objective "reality," members of a community construct their own reality. One who subscribes to this assertion rejects the idea that knowledge of mathematics can be transmitted from a teacher to a student. But if the subject matter has no reality independent of those who are teaching and learning it, and if learning is not the process of building more accurate representations of this reality, then what should teachers do, and how should they do it?

This question is at the heart of the controversy over the implications of constructivism for instruction in mathematics. It raises other questions about what it means to know and do mathematics, about the goals of school mathematics and the role of teachers in achieving those goals. We have found the work of Paul Cobb and his colleagues on the Second-Grade Mathematics Project, which will be discussed in detail later in this paper, particularly helpful at beginning to answer some of these questions.

Cobb (1988) outlines two important implications for teaching of adopting a constructivist orientation in favor of the more commonly held transmission model of teaching. The first is an acceptance of the idea that "[o]ne of the teacher's primary responsibilities is to facilitate profound cognitive restructuring and conceptual reorganizations" (Cobb, 1988, p. 89). The second is a shift in the focus of assessment of the results of instruction away from attention to acquisition and accurate use of procedures.

> "The assumption that there is a one-to-one correspondence between students' observable behaviors and the underlying conceptual structures does not follow from constructivism. It is quite possible for students to use the prescribed methods to solve a particular set of tasks on which they have received instruction without having developed the desired conceptual structures" (Cobb, 1988, p. 91).

These researchers find that accepting the assumptions of constructivism allows them to understand and portray classroom interactions in a coherent way. To do so, they define a "classroom mathematics tradition" as that often implicit set of social and mathematical assumptions and understandings, created and shared by the students and their teacher, that influence each individual's construction of knowledge (Cobb et al, 1992). These understandings and assumptions exert this influence "by constraining what can count as a problem, a solution, an explanation, and a justification" (Cobb et al, 1992, p. 575).

They then describe the traits of two contrasting traditions, which they call the "School Mathematics tradition" and the "Inquiry Mathematics tradition," using terms proposed by Richards (1991). Students and teachers in each of these traditions construct "meaningful" intersubjective knowledge, but what counts as meaning differs greatly between the two. In the school mathematics tradition, communication takes the form of instructions in the use of procedures brought to the students by the teacher. Mathematical "truth" is external and is neither explained nor justified; for the students in this tradition, understanding means being able to use these procedures successfully to meet the expectations of the teacher. (See also Schoenfeld, 1988; Doyle, 1988; Davis, 1989.)

On the other hand, students and teachers in an inquiry mathematics tradition work together to constitute provisional truths. Truth is intrinsically explainable and justifiable; students in this tradition develop "the ability to assess the legitimacy of each others' mathematical activity"

(Cobb et al, 1992, p. 594). The teacher's authority in such a class resides, not in her knowledge of the truth as defined by others, but in her ability to view developing truths within the classroom from the perspective of the larger mathematical community outside the classroom. Her role, then, is to judge whether these provisional truths "would be productive with regard to [students'] further learning and mathematical enculturation" (Cobb et al, 1992, p. 594) and to make instructional decisions that guide productive knowledge growth.

Constructivism, therefore, is a reconceptualization of how learners in a mathematical community come to know mathematics. This reconceptualization is the foundation for the vision outlined next.

The Resulting Vision

The resulting vision for mathematics education, based on a constructivist framework, is portrayed in two major documents from the National Council of Teachers of Mathematics: Curriculum and Evaluation Standards for School Mathematics (Commission on Standards for School Mathematics, 1989); Professional Standards for Teaching Mathematics (Commission on Teaching Standards for School Mathematics, 1991). NCTM is the professional organization of classroom teachers in the United States. The Council assembled the commissions that wrote these documents, because based on research, some of which we have cited, it recognizes the need to reexamine every assumption upon which the teaching of mathematics in the schools is based.

Curriculum and Evaluation Standards for School Mathematics. In a manner consistent with the tenets of constructivism outlined above, the authors of this document (a commission which included regular classroom teachers as well as university professors of mathematics and education and policymakers) ask its readers to recognize that mathematics is a changing, developing discipline developed by people whose individual understandings are actively constructed, rather than passively received. Mathematics is portrayed here as an experimental science, in which people engage -- individually and collectively -- in the search for patterns in numbers, shapes and data. (See also Hoffman, 1989; Schoenfeld, 1989; Steen, 1988.)

From this vantage point, the document articulates the following goals for school mathematics:

1. that they learn to value mathematics,

2. that they become confident in their ability to do mathematics,

3. that they become mathematical problem solvers,

4. that they learn to communicate mathematically, and

5. that they learn to reason mathematically (p. 5).

In order to accomplish these ambitious goals, the authors call for a curriculum that is much broader than arithmetic, and which includes a core of mathematical ideas that all students should have the opportunity to explore. They call for reduced emphasis on rote memorizing of procedural skills in favor of activities that promote understanding of, and connections between, important mathematical ideas. They assert that instruction should revolve around the investigation of problems out of which mathematical activity might grow, rather than repetitive practice of exercises taken out of context.

> "... we see classrooms as places where interesting problems are regularly explored using important mathematical ideas. Our premise is that **what** a student learns depends to a great degree on **how** he or she has learned it" (p. 5, emphasis in original).

> "[A]ctivities should grow out of problem situations ... experience with problems helps develop the ability to compute ... students need to experience genuine problems regularly. A genuine problem is a situation in which, for the individual or group concerned, one or more appropriate solutions have yet to be developed. The situation should be complex enough to offer challenge but not so complex as to be insoluble. "Commission on Teaching Standards for School Mathematics, 1989 p. 10)

The authors of the Standards also propose that assessment of students' mathematical knowledge be viewed as an integral part of instruction, rather than an activity that follows instruction. They suggest several ways to accomplish this, but stress that

> "[w]hatever the scheme, the results [of student assessment] should constitute an accurate and thorough indication of the mathematics that students know. Merely adding scores on written tests will not give a full picture of what students know. The challenge for teachers is to try different ways of grading, scoring, and reporting to determine the best ways to describe students' knowledge of mathematics ... (Commission on Teaching Standards for School Mathematics, 1989, p. 190).

Professional Standards for Teaching Mathematics. This document focuses, with the Curriculum and Evaluation Standards as the backdrop, on the special role of the teacher in the process of change. The authors begin with the statement that "Teachers are key figures in changing the ways in which mathematics is taught and learned in schools" (Commission on Teaching Standards for School Mathematics, 1991, p. 2). They assert that teachers are professionals who have to be able to make instructional decisions in several important areas. Teachers' overall goals must be to

> "[help] students work together to make sense of mathematics ... to rely more on themselves to determine whether something is mathematically correct ... learn to

reason mathematically ... learn to conjecture, invent, and solve problems ... to connect mathematics, its ideas, and its applications." (pp. 3-4).

If exploration of problems is the appropriate format for mathematical activity in classrooms, then teachers must be able to select stimulating and interesting tasks for students to explore. In addition to providing opportunities for students to deepen their understanding of important mathematical ideas, their connections with students' prior knowledge, and their applications, teachers must establish an environment that encourages mathematical exploration. Teachers will be responsible for orchestrating classroom discourse and using technology and other tools to guide individual, small-group, and whole-class work in ways that promote investigation of mathematical ideas. However,

> "A high-quality mathematics experience is not determined simply by the presence of computers or calculators or the use of small groups, manipulatives, or student discussions. The nature of the mathematical task posed and what is expected of students are critical aspects against which to judge the effectiveness of the lesson." (Commission on Teaching Standards for School Mathematics, 1991, p. 5)

Finally, teachers will be required to devise ways to integrate assessment of students' learning into instruction using multiple sources of information, both formal and informal.

Related documents. We should mention that several other documents have been produced which outline the need for reform and means by which to accomplish it. Two examples are Everybody Counts: A Report to the Nation on the Future of Mathematics Education (Mathematical Sciences Education Board, 1989) and Reshaping School Mathematics: A Philosophy and Framework for Curriculum (Mathematical Sciences Education Board, 1990). There is a substantial amount of agreement between the recommendations made in these documents and those outlined above. They are based on the constructivist framework discussed earlier; they share the perspective that mathematics is a dynamic, experimental, useful, socially constructed discipline; they embrace the notion that all students should have access to this essential discipline. This reflects a remarkable consensus about the goals of reformers of school mathematics teaching and learning.

The crucial question raised by these documents, and the resulting vision they present, is how to accomplish the fundamental changes that are needed. In the next section we outline several research programs that have been designed and conducted in regular classrooms. They are based on assumptions about mathematics and how it is learned that are very much in line with those that guide the Standards.

Getting From Here to There

The school reform movements in the United States are relatively recent phenomena (Cohen, 1988). Up until the beginning of the twentieth century, schools were a place for

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"telling," a place where obedience, copying, remembering, and reciting were considered "learning." In this way they reflected the ways in which learning occurred in other aspects of the society, such as at homes and religious institutions. "School boosters" saw education as a way to "turn a rough and divided collection of peoples into a self-governing political community" (Choen, 1988, p. 27). "School-haters," on the other hand, valued the experience of life as the greatest teacher, and saw schools as stifling places. Cohen credits Dewey with merging these two perspectives into a vision in which experience would be the basis for learning in schools.

The notion that schools could provide valuable experiences for students led to the push for changing the way schools operated. This in turn would have resulted in a dramatic change in the role of the teacher. Instead of telling, they would have to provide contextualized, structured learning experiences for their students. "[Dewey] helped make it legitimate to expect intellectual adventure as a regular part of any neighborhood school" (Cohen, 1988, p. 30).

Despite these expectations, however, Cohen asserts that schooling has changed little since then. He finds faults with all of the reasons (school organization, the conditions of teaching, flaws in reform, and lack of incentives for change) given for the stability of school processes, noting that "there are equally convincing examples of traditional teaching that persists when the explanatory factors are reduced or removed" (p. 37). Cohen (1988) believes that

> "... each account assumes few barriers to adventurous teaching within teaching itself. All focus on barriers outside of teaching, in its circumstances. Yet to believe that any teacher can produce such classes is not to decide how easy it would be. Would it be easy or difficult? One very curious feature of virtually all reformist writing about teaching, from Dewey to Bruner, is that no one has ever tried to answer this question. Indeed, no one has ever considered it worth asking." (p. 38)

Cohen's remarks form the backdrop for this three-part section which seeks to answer, at least in part: How difficult is it for teachers to change the nature of what is taught in the mathematics classroom and how they teach? (This is very different from asking how difficult it is to change teachers.) Romberg and Carpenter (1986) note that "We currently know a great deal more about how children learn mathematics than we know about how to apply this knowledge to mathematics instruction" (p. 859). The first section describes two research programs in which teachers are the focus of attempts to change the nature of mathematics teaching and learning. The focus of each of these research programs is on teachers in regular classrooms who are learning about their students' learning and, in the process, are learning how to change their teaching. This section is followed with examples of the classroom teaching of Magdalene Lampert and Alan Schoenfeld, two distinguished researchers who have critically examined, and written extensively about, their own teaching of mathematics, providing enticing glimpses into very different kinds of classroom environments. This section concludes by examining the complex issue of using textbooks as the messengers of change.

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Research on Mathematics Teaching

Cognitively-Guided Instruction (CGI). The Cognitively-Guided Instruction Program, centered at the University of Wisconsin, Madison, focuses on first-grade teachers and their students (Carpenter, Fennema, Peterson and Carey, 1988; Carpenter, Fennema, Peterson, Chiang and Loef, 1989; Peterson, Fennema, Carpenter and Loef, 1989; Carpenter and Fennema, 1991). Forty first-grade teachers from 24 schools in or near Madison participated in one of these studies (Carpenter et al, 1989). Twenty of the teachers were randomly assigned to the control group to which no instruction was given, and twenty were randomly assigned to the treatment, a month-long summer workshop "designed to familiarize them with the findings of research on the learning and development of addition and subtraction concepts in young people and provide them with an opportunity to think about and plan instruction based on this knowledge" (Carpenter et al, 1989, p. 503).

> "The purpose of the study was to investigate whether providing teachers access to explicit knowledge derived from research on children's thinking in a specific content domain would influence the teachers' instruction and their students' achievement. We hypothesized that knowledge about differences among problems, children's strategies for solving different problems, and how children's knowledge and skills evolve would affect directly how and what teachers did in classrooms. We also hypothesized that such knowledge would affect teachers' abilities to assess their own students, which would be reflected in teachers' knowledge about their students. Knowledge about their students would allow teachers to better match instruction to students' knowledge and problem-solving abilities. As a consequence, students' meaningful learning and problem-solving in mathematics would be facilitated." (Carpenter et al, 1989, p. 500)

During the summer workshop, teachers were provided, and given opportunities to reflect on, summaries of research; they viewed videotapes of children solving problems; and they were given the opportunity to interview two children. They were encouraged to develop plans for instruction, and they met with the project staff each week to discuss their progress. After the workshop ended, only informal contact with these teachers was maintained throughout the school year.

Classrooms of both experimental and control group teachers were systematically observed throughout the school year, and at the end of the year a series of instruments were administered to the teachers and students in both groups, in order to assess teachers' knowledge and beliefs about mathematics, student achievement, and the effects on students' confidence and beliefs.

The classroom observations indicated that, even though specific instructional patterns were not prescribed, CGI classes spent more time talking about problems and discussing alternate solutions than did the control classes. The students in the two groups performed comparably on tests of computational proficiency, but the CGI students performed better on complex addition and subtraction problems that are not typically part of first-grade curricula. The CGI students scored higher on measures of number fact knowledge, problem-solving, reported understanding, and reported confidence in their problem-solving abilities.

The researchers concluded that providing teachers access to research findings on the "learning and development of addition and subtraction concepts in young people and [providing] them with an opportunity to think about and plan instruction based on this knowledge" (Carpenter et al, 1989, p. 503) made a difference in what teachers emphasized in their classes and how they conducted mathematics lessons. The researchers also concluded that such changes in teacher practice resulted in an increase in student content knowledge and problem-solving ability.

In two other studies conducted as part of the CGI program, Carpenter, Fennema and Peterson investigated the pedagogical content knowledge and beliefs of elementary mathematics teachers (Carpenter, Fennema, Peterson and Carey, 1988; Peterson, Fennema, Carpenter and Loef, 1989). The subjects in the first of these studies (Carpenter et al, 1988) were first-grade teachers who were teaching addition and subtraction to their students. The teachers were asked to classify problems according to how difficult they thought they would be for their students. They were also to identify the strategies they thought their students would use to solve these problems. Then, the students were asked to solve the problems, and the relationships between the teachers' expectations and actual student performances were examined.

Analysis of teachers' classification of these problems showed that most teachers could distinguish among some of the basic problem types encountered, but those distinctions were not made based on a coherent conceptual framework. Further, the teachers "generally did not categorize problems in terms of the strategies that children use to solve them" (Carpenter et al, 1988, p. 398). So, the teachers in this study lacked the type of knowledge provided to the experimental teachers in the prior study. The researchers found no significant relationship between either the teachers' general knowledge of problems, their awareness of problem difficulty, or of strategies their students might use, and the achievement of their students; however, there was a significant relationship between teachers' predictions of their students' success and actual student achievement.

As in the prior study, these preliminary results seem to point to the importance of teachers' possession of a rich knowledge base that includes the students' perspectives on problem difficulty and strategy use. Unlike the prior study, however, the researchers found no relationship between teachers' knowledge of the strategies their students would use and student achievement. They speculate that this may be because the teachers make instructional decisions based on their perceptions of student difficulty rather than on student strategy use because of the teachers' lack of understanding of strategy use in general. The researchers also believe that the lack of relationship could possibly be explained by the difficulties involved in assessing teachers' knowledge of the strategies their students use.

In the second of these studies (Peterson et al, 1989), the researchers classified their first grade teachers as having either cognitively-based (CB) beliefs about mathematics (i.e., that children construct their own knowledge, that instruction should facilitate this construction, that this development should serve as the basis for sequencing instruction, and that understanding and problem-solving are the goals of this instruction) or less cognitively-based (LCB) beliefs. They found significant relationships between these belief systems and student problem-solving achievement.

The CB teachers in this study conducted their classes in ways similar to those advocated by the Standards and similar to the experimental group in the first CGI study. They made extensive use of word problems as the context of instruction. They spent time developing students' counting strategies before drilling number facts. The students of CB teachers performed better on problem-solving tasks than did students of LCB teachers, and did as well on computational exercises, despite CB teachers' reports of placing the least emphasis on their students' acquisition of such skill. Thus, this study's findings concur with those of the first CGI study showing that placing emphasis on understanding and problem-solving led to improvements in the conceptual as well as the procedural knowledge of their students, and that this emphasis is directly related to the pedagogical content knowledge and beliefs of teachers.

Second-Grade Mathematics Project. The Second-Grade Mathematics Project, our second major study in which teachers are the focus of attempts to change the nature of mathematics teaching and learning, focused on second-grade teachers (and their students) who were involved in project centered at Purdue University (Cobb et al, 1991a; Cobb et al, 1991b; Wood et al, 1991). During the first year of the project, researchers interviewed second-grade students in order to find out about their knowledge of arithmetic, spatial memory, and visualization. This was followed by a year-long teaching experiment, in which project staff collaborated with one second-grade teacher to develop materials and instructional approaches for her class. A full-scale assessment study, involving ten second-grade teachers from three schools, and their 187 students, was conducted during the third year of the project.

In the second phase of the study, instructional activities were designed within a "socioconstructivist" framework; the researchers asserted that students both individually construct, and collectively negotiate, mathematical meaning. The activities were based (when possible) on results from research on the processes by which children develop understanding of particular mathematics concepts. The researchers established several criteria that each of these activities had to meet. First, they had to be accessible, on some level, to students at different places conceptually. Second, they had to offer the chance for development in tandem of both conceptual and procedural knowledge. A third criterion was that the activities had to address the typical objectives of second-grade mathematics. The project directors recognized that the results of the project would have to include increases in scores on commonly-used measures. Finally, the activities had to offer the chance for both small-group and whole-class discussions about a variety of ideas about, and approaches to, their completion.

During the summer prior to the assessment project, the 10 project teachers participated in a week-long summer institute, in which "the basic goal [was] to help teachers consider whether aspects of their current practice might be problematic" (Cobb et al, 1991a, p. 106). The teachers viewed videotapes of lessons, worked with individual students, and reflected on these activities with project staff, who decided to advocate particular instructional approaches:

> Our goal in being relatively prescriptive with regard to pragmatic issues involving classroom management and the negotiation of classroom norms was not to program teachers to do it in a certain way. Rather, it was to make it possible for teachers to concentrate on children's mathematical activity rather than on management issues when they begin to use the instructional activities in their classrooms. In effect, we were prescriptive so that the teachers' classrooms would be conducive learning environments for them as well as for their students during mathematics instruction. (Cobb et al, 1991a, p. 108).

At the end of the school year, the 10 project classes were compared to 8 nonproject classes on several measures of student achievement. The first was the state-mandated test containing items from the California Achievement Test (CAT) and divided into two subtests: computation, and concepts and applications. The second instrument was created by the researchers; it contained two subtests, the instrumental scale and the relational scale. The instrumental scale could be completed successfully without understanding. The relational scale was designed to assess "students' understanding of place-value numeration and computation in nontextbook formats" (Cobb et al, 1991b, p. 15).

Similar to the CGI studies' findings, the scores on the first part of each test were equivalent for students in both the project classes and the nonproject classes. However, those in the project classes scored, on average, almost a full grade-equivalent higher (4.54 to 3.73) than those in the nonproject classes on the concepts and applications subtest of the state test. The project students' scores on the relational subtest of the second measure were a full standard deviation higher than scores of the nonproject students.

When students' solution methods were analyzed, researchers noted that project students were able to use their individually constructed, but nonstandard algorithms quite flexibly when presented with problems in different formats. In contrast, nonproject students used standard algorithms more often than project students when presented with problems in standard format, but their use of these algorithms dropped off considerably as tasks became less familiar. The researchers view these results as a challenge to the assumption underlying traditional instruction that students who are taught standard algorithms will be able to apply them in a variety of contexts.

The teachers of both the project and nonproject classes were asked to complete a beliefs questionnaire, and there was a marked difference between the two groups. Project teachers' beliefs were much more consistent with the socioconstructivist point of view. These teachers, who volunteered to participate in the project, might have done so because of their beliefs, but results from the teaching experiment (Wood et al, 1991) that preceded the assessment study indicate that the teacher in that precursor to the project changed her beliefs about teaching and learning mathematics. Participation in the project placed her in the position of having to resolve conflicts and dilemmas between her initial beliefs and the project's emphasis on children's construction of meaning.

The teacher was forced to back away from providing procedures to her students; instead, she listened to her students' thoughts and ideas. She discovered that her students' ideas were more complex than she had imagined, and that she could encourage their further development. She often heard student comments that indicated incorrect conceptions, but she began to realize that they made sense to her students. What she needed to do was to help her students to resolve the conflicts that their conceptions created, rather than trying to impose correct conceptions. As the year progressed, she wrestled with a conflict between her goal of having her students learn standard algorithms and the project's goal of having students construct their own algorithms. She came to realize that it was through group interaction and negotiation with her students that she and her students could arrive at shared conceptions.

Cobb and his colleagues note that their results are consistent with those of the CGI stuaies, which they found "particularly encouraging given that the two research groups worked at different grade levels and adopted different approaches to teacher development" (Cobb et al, 1991b, p. 25). They conclude by noting that, while their study was not meant as a test of the recommendations in the NCTM Standards,

> "The compatibility of the project with [the Standards] includes a socioconstructivist view of learning; an emphasis on mathematical communication, problem solving, and reasoning; and an attempt to encourage the development of both relational beliefs about mathematics and the goals of learning and understanding as ends in themselves" (Cobb et al, 1991b, p. 26).

These successful first steps to reform in regular classrooms suggest that teaching as envisioned in the NCTM Standards is possible in regular classrooms. In each of these studies, teachers were encouraged to concentrate on their students' thinking about mathematical ideas. They were helped to provide a mathematical environment in which these mathematical ideas could be explored by groups of students. The particulars of the two major studies differed in one important respect. Detailed cognitive models of the processes by which students acquire knowledge of the concepts being taught were available to the CGI researchers, and they were able to provide these models to the teachers in the experimental group. The content for the Second-Grade Mathematics Project has not been so extensively analyzed. Lampert (1991a) notes that for most of the content domains of school mathematics, "nothing like the 'problem types' for addition and subtraction exists" (p. 141). However, both her own teaching of fourth- and fifth-grade mathematics, and the college-level problem-solving teaching of Schoenfeld, provide evidence of promising approaches to helping students to make meaningful sense of mathematical ideas.

The research and teaching of Lampert, Schoenfeld. In this section, we provide extended excerpts from the teaching of these two investigators. Reading these accounts places one in their classrooms and gives some sense of how mathematics classes of the kind outlined in the NCTM

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Standards might look. Their long-term research programs, conducted in regular classrooms, are efforts to change their own teaching, and to reflect on that work, without the benefit of detailed cognitive models of how students construct the mathematical ideas they sought to teach. Their efforts constitute proof that it is possible to establish very different and productive climates in which students do mathematics.

Lampert has taught fourth- and fifth-grade mathematics on a daily basis for a number of years. She has written extensively about both her classroom experiences and those of her students (Lampert, 1986; 1990; 1991a; 1991b). In the excerpt that follows, she and her fifth-grade students are exploring the meaning of exponents.

> "When I asked if anyone had any ideas about 7^4, there was quick agreement that [the last digit] should be 1 and I asked for proof. Gar said, "7 times 7 is 49. And 9 times 9 is 81. So take the 1." Embedded in this argument is the assumption that 7^4 = 7^2 x 7^2 and that all you need to attend to is the last digit all the way through the procedure. Gar multiplied 9 x 9 to arrive at 1; he did not multiply 49 x 49, and then try to figure out the answer to that. Versions of this argument were given and elaborated by other students. There was a repetition in much of what they said of the language that had been used in discussing 5^4, but the same terms and sentence structures were being used by different students. By this point, nearly everyone had had something to say.
>
> Then I asked, to further elicit their conjectures about how exponents work, "What about 7 to the fifth power?" Several students raised their hands after a few moments, and the ones who were called on said in quick succession:
>
> Arthur: I think it's going to be a 1 again.
>
> Sarah: I think it's 9.
>
> Soo Wo: I think it's going to be 7.
>
> Sam: It is a 7.
>
> "I wrote on the board, "7^5 = 1? 9? 7?" and said, "You must have a proof in mind, Sam, to be so sure," and then I asked, "Arthur, why do you think it's 1?"
>
> The following discussion ensued as the students attempted to resolve the problem of having more than one conjecture about what the last digit in 7 to the fifth power might be. It was a zig-zag between proofs that the last digit must be 7 and refutations of Arthur's and Sarah's alternative conjectures. The discussion ranged between observations of particular answers and generalizations about how exponents -- and numbers in general -- work. Students examined their own assumptions and those of their classmates. I assumed the role of manager of the

discussion and sometimes participated in the argument, refuting a student's assertion.

Teacher: Arthur, why do you think it's 1?

Arthur: Because 7^4 ends in 1, then it's times 1 again.

Gar: The answer to 7^4 is 2,401. You multiply that by 7 to get the answer, so it's 7 x 1.

Teacher: Why 9, Sarah?

Theresa: I think Sarah thought the number should be 49.

Gar: Maybe they think it goes 9, 1, 9, 1, 9, 1.

Molly: I know it's 7, 'cause 7 ...

Abdul: Because 7^4 ends in 1, so if you times it by 7, it'll end in 7.

Martha: I think it's 7. No, I think it's 8.

Sam: I don't think it's 8 because, it's odd number times odd number and that's always an odd number.

Carl: It's 7 because it's like saying 49 x 49 x 7.

Arthur: I still think it's 1 because you do 7 x 7 to get 49 and then for 7^4 you do 49 x 49 and for 7^5, I think you'll do 7^4 times itself and that will end in 1.

Teacher: What's 49^2?

Soo Wo: 2,401.

Teacher: Arthur's theory is that 7^5 should be 2401 x 2401 and since there's a 1 here and a 1 here...

Soo Wo: It's 2,401 x 7.

Gar:	I have a proof that it won't be a 9. It can't be 9, 1, 9, 1, because 7^3 ends in a 3.
Martha:	I think it goes 1, 7, 9, 1, 7, 9, 1, 7, 9.
Teacher:	What about 7^3 ending in 3? The last number ends in ... 9 x 7 is 63.
Martha:	Oh ...
Carl:	Abdul's thing isn't wrong 'cause it works. He said times the last digit by 7 and the last digit is 9, so the last one will be 3. It's 1, 7, 9, 3, 1, 7, 9, 3.
Arthur:	I want to revise my thinking. It would be 7 x 7 x 7 x 7 x 7. I was thinking that it would be 7 x 7 x 7 x 7 x 7 x 7 x 7 x 7.

"Once Arthur revised his idea that the last digit should be 1 there were no further disagreements in the class, with the conclusion that it should be 7." (Lampert, 1990, pp. 50-51)

Several characteristics of Lampert's classroom environment are apparent in these exchanges. The first is the roles played by the teacher and her students. Her role is that of problem poser and manager of the ensuing discussion. She provided her students with an open-ended question for them to consider, and from that point on she posed questions, restated student ideas, and redirected the focus of the discourse. Her choice of problem was based on her own knowledge of the mathematical structures she wanted her students to think about. It was also based on her knowledge of what would be accessible to her students, and what would allow them to explore these structures from various perspectives (Lampert, 1991b).

The second striking characteristic of this classroom interlude is the nature of the discourse engaged in by her students. They freely offered ideas, challenged each others' assertions, and revised their thinking, needing only the occasional input from the teacher. Lampert has been able to negotiate a classroom environment in which students think about ideas in critical ways, yet the environment is a trusting one. She has provided protection against social power in ways that have allowed her students to "stand to the side" of their own ideas (Leinhardt, 1992).

Finally, the students in this class are engaged in the kind of mathematical sense-making that mathematicians themselves engage in. They gathered data, looked for patterns, offered "theorems," proved (or disproved) them, and arrived at conclusions that were agreed upon by the group. In this vignette, Lampert has modeled the role of the teacher outlined by NCTM's Professional Standards for Teaching Mathematics and her students can be seen meeting the goals for students outlined in NCTM's Curriculum and Evaluation Standards for School Mathematics.

Schoenfeld has also written extensively about his problem-solving course at the University of California at Berkeley (Schoenfeld, 1992b; 1987, 1985; forthcoming). The descriptions included below illustrate two aspects of his classroom "engineering," and some indication of its consequences.

"In the course described here, explicit deflection of teacher authority began the second day of class when a student volunteered to present a problem solution on the board. As often happens, the student wrote the argument on the board focusing his attention on me rather than on the class; when he finished, he waited for my approval or critique. Rather than provide it, however, I responded as follows:

> "Don't look to me for approval, because I'm not going to provide it. I'm sure the class knows more than enough to say whether what's on the board is right. So (turning to the class) what do you folks think?"

"In this particular case the student had made a claim which another student believed was false. Rather than adjudicate, I pushed the discussion further: How could we know which student was correct? The discussion continued for some time, until we found a point of agreement for the whole class. The discussion proceeded from there. When the class was done, (and satisfied) I summed up.

This problem discussion illustrated a number of important points for the students, points consistently emphasized in the weeks to come. First, I rarely certified results, but turned points of controversy back to the class for resolution. Second, the class was to accept little on faith ... but instead was to adopt the standard that our discussion must be grounded in solidly understood mathematics. Third, my role in class discussion would often be that of doubting Thomas. That is, I often asked "Is that true? How do we know? Can you give me an example? A counterexample? A proof?" -- both when the students' suggestions were correct and when they were incorrect. (A fourth role was to ensure that the discussion was respectful -- that it's the mathematics at stake in the conversations, not the students!)

"The pattern was repeated consistently and deliberately, with effect. Late in the second week of class, a student who had just written a problem solution on the board started to turn to me for approval, and then stopped in mid-stream. She looked at me with mock resignation and said, "I know, I know." She then turned to the class and said, "O.K., do you guys buy it or not?" (After some discussion, they did.) (Schoenfeld, forthcoming, pp. 12-13.)

Schoenfeld's students learned very quickly that he would not be the ultimate arbiter of the correctness of their work; rather, they would work together to determine, based upon what they knew and what they could justify to the others, whether assertions were correct. In this way, Schoenfeld's teaching is quite similar to Lampert's: both take a constructivist approach to classroom instruction. Each plays a very different role from that which is familiar to, and expected by, most students. As a result, the students also have a very different role, that of active participants in the collective development and justification of mathematical ideas. The students in this class might not have discovered any new or important mathematics, but for them the mathematical ideas they constructed were both new and important because they had built these understandings together.

These researcher-teachers have, through thorough analyses of mathematics content and what it means for individuals in an "intellectual community" to come to know that content, demonstrated that meaningful mathematical activity among teachers and students in regular classrooms is possible. However, as Lampert notes, several daunting questions remain.

> "What do my students take away from this activity into other classrooms they will inhabit? Or out of school into the world of work and family? ... Answering the question of whether authentic mathematical activity is possible in schools does not by itself produce a solution to these problems." (Lampert, 1990, p. 59)

Text Development Projects

Can new textbooks and other curriculum materials carry the message of reform, and what roles do they play in affecting reform? Given the large number of curriculum projects in mathematics that have been undertaken in recent years, this would seem to be an important question. In this section we explore the complicated relationship between textbook adoption, based on policy mandates from outside the classroom, and change in the classroom.

Recently, the state of California undertook an ambitious project to change the teaching of mathematics in its public schools. The state published a Mathematics Framework (California Department of Education, 1985) in which it outlined a radically different view of mathematics, how it is learned, and how it should be taught. A series of preliminary studies of the effects of the implementation of the California Mathematics Framework were recently published in a special issue of the journal Educational Evaluation and Policy Analysis. In her introductory article to this volume, Darling-Hammond (1990) states that the articles and case studies contained therein "contribute to and strengthen a newly-emerging paradigm for policy analysis -- one that attends to policy conditions and contexts, the nature of teaching, and the process of change -- while it illuminates the course of a particular policy of great national interest" (p. 233).

The California Study of Elementary Mathematics looked at second- and fifth-grade classrooms in two schools in each of two school districts in California (Peterson, 1990a). Teachers were interviewed, classes were observed at two times during the school year, and five cases were developed and reported in this special journal issue. Taken together, these case studies paint a picture of teachers wrestling with (yet another) new policy, but they do so from the perspectives of these teachers. They provide important glimpses into the thinking of teachers who are struggling with change.

Mark Black was an experienced fifth-grade teacher whose beliefs about mathematics were at odds with those of the Framework (Wilson, 1990). As a result, he transformed the text adopted by the district into a more traditional text, by leaving out or "streamlining" lessons that, for example, used manipulatives. Four perceived conflicts were apparent in conversations with Mark Black and observations of his teaching. He felt pressed by time, tests, and the pressures of parental expectations. This conception of mathematics, how it is learned, and how it is taught, were at odds with the message of the Framework. He was not familiar with the alternate pedagogical strategies called for in the text and felt caught between contradictory calls for reform. Calls for improved scores on traditional tests of procedural skill seemed to conflict with the Framework's emphasis on conceptual understanding.

Carol Turner, on the other hand, was very comfortable with the Framework's message; in fact, she saw it as reinforcing her own approach to teaching second-grade mathematics (Ball, 1990). The result was that the policy initiative had little impact on her teaching. When she was observed, however, it became clear that while she wanted students to be engaged because they learned better when they were, what they were engaged in, and what it meant to be engaged, were different from what the policy's framers intended. The type and sequence of Carol's questions acted as "templates" for certain kinds of short responses, precluding "mathematical speculation, conjecture and invention. ... Just as there is a right answer, there also is a right explanation" (p. 268). Therefore, depending on the lens through which her teaching was viewed, Carol either implemented a policy that called for teaching similar to that which she was already doing, or she missed the message, implicit in the reform recommendations, that she must rethink the beliefs and knowledge upon which her practice is based.

The case of Joe Scott (Wiemers, 1990) portrays an experienced fifth-grade teacher who liked mathematics as a student (it was his favorite subject), and who was confident and well-respected in his school as a mathematics teacher. He served on the committee that helped to choose the book he was using.

Joe was a traditional teacher. "Energy and anxiety, quickness and competition are constant features of Joe's mathematics class" (Weimers, 1990, p. 298). He was determined to follow the text carefully, and he provided clear anticipatory sets and direct instruction of the lessons. He had not read the Framework; he interpreted the message of the policy in a limited way, to provide his students with application skills. The text contained lessons that stressed this message, and Joe added them to his teaching when he had time.

The policy did result in changes in Joe's teaching, but Wiemers (1990) questions whether these small, incremental changes, made because Joe is committed to providing his students with the tools to be successful, will add up over time to changes in Joe's beliefs about mathematics and mathematics learning and teaching.

Mrs. Oublier felt as though she had revolutionized her mathematics teaching (Cohen, 1990). Her second-grade classroom had moved, in her 4 years of teaching, from a worksheet-driven, procedure-oriented room to one in which students worked with manipulatives and where the teacher worked to have her students understand how arithmetic worked. She was excited about what her students, and she, had accomplished. However, Cohen points out that

... she used the new materials, but used them as though mathematics contained only right and wrong answers. She has revised the curriculum to help students understand math, but she conducts the class in ways that discourage exploration of students' understanding.... Her classes present an extraordinary melange of traditional and novel approaches to mathematics instruction (p. 328).

He notes that her classes proceeded smoothly, even though there was this tension between claims to teach for understanding on the one hand, and the apparent lack of structure to facilitate discourse on the other. In Cohen's view, Mrs. O's lack of mathematical knowledge and narrow view of mathematical understanding -- the lack of a "mathematical and pedagogical infrastructure" (p. 335) -- pushed these tensions beneath the surface. He claims that, if one were to teach for understanding in the spirit of the Framework, more rough going would be evident.

"Had Mrs. O known more math, and tried to construct somewhat more open discourse, her classroom would not have run so smoothly. Some of the tensions that I noticed would have become more audible and visible to the class. More confusion and misunderstanding would have surfaced. Things would have been rougher, potentially more fruitful, and vastly more difficult." (Cohen, 1990; p. 339)

After 2 years as a basic skills teacher, Cathy Swift was in her second year of teaching second grade (Peterson, 1990b). She was an English major in college and was excited about the literature-based reforms that were also being implemented by the district; she was not, however, very confident in her knowledge of mathematics or ability to implement the Framework's recommendations. She had not read the document, but she had a new textbook, which she followed carefully.

As a result, Cathy added the use of manipulatives, group work, and problem-solving to her classes. These add-ons were the first to be dropped when time became a problem, or when they became too hard for her students. Cathy's classes were heavily influenced by the basic skills program she taught for several years. She relied on direct instruction and mastery learning techniques in her teaching.

Several uncertainties are discussed by Peterson (1990b) in this case. First, Cathy was uncertain about her own knowledge of mathematics, as well as her knowledge of how to teach problem-solving. She sensed conflicts between the district's mastery learning approach and the new goals of teaching for understanding. Second, she sensed a conflict between the pacing charts that were in common use and the time needed for students to really understand. She also needed time to figure out how to teach toward this new goal. Finally, she was unsure whether her work was accomplishing its goals, and she was unsure how to proceed.

None of the teachers whose cases are presented here had actually read the Framework document; each had the policy transmitted to them through the textbook adopted by their district. Each of the teachers filtered this message through their existing practice, their personally held beliefs about mathematics learning and teaching, and the circumstances of their work. Some developed new practices in response to the policy. One transformed his new text into a traditional one; one remained virtually unchanged in her teaching. Each of these practices was different, and each differed in important ways from that which the writers of the Framework intended.

Several important themes emerge from these cases. One is that teachers' knowledge and beliefs about mathematics, and about mathematics teaching and learning, were crucial factors in determining what changes, if any, that the teachers made in the content and structure of their classes. A traditional view of mathematics as a set of topics to be drilled would encourage adaption of a new text's activities, use of manipulatives and opportunities for group work as additions to a bag of tricks rather than as fundamental changes in the message sent to students about mathematics. Cohen and Ball (1990b) point out that

> "Estimation, manipulatives, and problem solving became new discrete topics, rather than -- as the Framework's authors appeared to intend -- elements useful in all sorts of mathematical reasoning. These teachers had implemented an element of the Framework, in a sense; their lessons had some of the new content. But that new content was organized within the existing structure of traditional school mathematics." (1990b, p. 351).

Another important point of these cases is that teachers work in a context that is complex and often contradictory. They have personal and professional histories, and are at the focus of influences that pull them in several directions. Yet teachers must act.

> "... teachers are busy and engaged actors, who must make their classrooms work. To do so, they must balance all manner of contradictory tendencies (Fenstermacher and Amarel, 1983; Berlak and Berlak, 1981; Lampert, 1985). If teachers could not make past and present cohere, they would be unable to do anything at all in their classes. ... changing one's teaching is not like changing one's socks. Teachers must construct their practices gradually, out of their experiences as students, their professional education, and their previous encounters with policies designed to change their practice. Teaching is less a set of garments that can be changed at will than a way of knowing, seeing and of being. And unlike many practices, teaching must be jointly constructed by both teacher and students. So if teachers are to significantly alter their pedagogy, they must come to terms not only with the practices that they have constructed over decades, but also with students' practices of learning, and the expectations of teachers entailed therein." (Cohen and Ball, 1990a, pp. 252-253)

These studies suggest that the textbook might not be the best messenger of change. The message itself is bound to be personalized in unanticipated ways by teachers who have unique personal histories and mathematics knowledge stores, and who work in specific and contradictory contexts.

Change Projects

New and innovative textbooks are being written which are based on assumptions and goals similar to those of the NCTM Standards documents. With the results of the California Framework Study in mind, we cautiously begin this section by citing two promising curriculum projects. The first is the University of Chicago School Mathematics Project (UCSMP), which has worked since 1983 to develop a textbook series for grades 7-12, curriculum materials for grades K-2, a program to train elementary teachers as mathematics specialists, and to collect and make available resources for teachers and educators from foreign curriculum materials and research.

The beliefs that guide this work (Usiskin, 1990) are well-aligned with those espoused by the Standards documents, including the beliefs that all students are capable of learning a broad set of mathematics concepts, and that computers and calculators can play an important role in this learning. Evaluation of the project materials has proceeded along with the development of those materials; this parallel effort contributed in important ways to the published products (Stodolsky & Hedges, 1990). Students who used the UCSMP Algebra textbook, for example, performed as well as those in comparison classes on standardized measures of algebra achievement, and they performed much better on measures of achievement in innovative topics covered by the text.

The second curriculum project that we wish to cite here is Computer Intensive Algebra (CIA)(Heid, 1988; Zbiek and Heid, 1990; Sheets and Heid, 1990). This first-year algebra course re-sequences the traditional topics of algebra, solving problems before stressing facility with symbolic procedures, the focus in traditional algebra classrooms. The course uses computer tools that graph functions, manipulate symbols, create tables of values, and fit curves to data to support this realistic problem-solving activity, using the concept of functions as the organizing theme (Kieran, 1990). Students in the CIA classes did as well on departmental final exams as did students in comparison classes. They also "outperformed their counterparts on such mathematical modeling goals as constructing, interpreting and linking representations ... [and] surpassed conventional classes in improvement of problem-solving abilities" (Kieran, 1990, p. 112).

In addition, many other projects, both large and small in scale, are in various stages of development, implementation, and evaluation. What follows is an abbreviated list to which we have added relevant information that was readily available.

- State Systemic Initiatives. The U. S. National Science Foundation has awarded large grants, with matching funds provided by those states, for statewide reform of mathematics teaching and learning. Ten states were awarded grants during the first cycle; 10 more received funding during the second cycle.

- Interactive Mathematics Project. A 4-year problem-centered, integrated mathematics curriculum for grades 9-12. (Project Directors: Lynne Alper, Sherry

Fraser, EQUALS, Lawrence Hall of Science, UC-Berkeley; Dan Fendel, Diane Resek, San Francisco State.)

• QUASAR [Quantitative Understanding: Amplifying Student Achievement and Reasoning]. (Project Director: Edward A. Silver, University of Pittsburg.)

• Jasper Woodbury Problem Solving Series, an example of a video-based instructional macrocontext for complex problem generation and problem solving. (Cognition and Technology Group at Vanderbilt University.)

• Algebridge, developed by Educational Testing Service and the College Board to help students master the change of thinking required in algebra. (Project Director: Paul Ramsey. Published by Janson Publications, Providence, RI.)

• The Used Numbers Project, an elementary-school data analysis program. (Authors are Susan Jo Russell and Rebecca Corwin of Technical Education Research Center (TERC), published by Dale Seymour Publications, Palo Alto, CA.)

• Enhancing Teacher Professionalism through Collaborative Curriculum Development in Mathematics. (Project Directors: Thomas L. Good, Mary McCaslin, Barbara J. Reys, University of Missouri-Columbia.)

• Thinking Mathematics, a collaboration between the Learning Research and Development Center (LRDC) at the University of Pittsburg and the American Federation of Teachers. Teachers and researchers interpret results of research and the implications for practice. (Project Director: Barbara Grover, LRDC.)

• PRIME: Project for the Improvement of Mathematics Education. A teacher education project designed to bring this important component of reform in line with NCTM Standards. (Project Director: Susan J. Lamon, Marquette University, Milwaukee, WI.)

• The New Standards Project, a partnership of 17 states and 6 major school districts that have joined together to develop alternative approaches to setting education standards and assessing student achievement. Mathematics component uses NCTM Standards. (Project Directors: Lauren Resnick and Marc Tucker.)

CURRICULUM REFORM IN SCIENCE

Although there are many ties between education in mathematics and science, there are many aspects of education and its reform that are very subject-specific. As a result, the following section on curriculum reform in science has some similar themes but will reflect the specific characteristics of science, a disciplinary area having many differences from mathematics.

Historical Perspective

While science education reform is not new, current reform efforts differ from earlier reforms, especially the reform efforts from the sixties in some very specific and significant ways. The current reform efforts are informed by new understandings of how students learn, somewhat different goals for science education, a different social and economic context, and a much fuller understanding of what it takes to put reforms into place. Nonetheless, the common elements are sufficient enough that this discussion will begin with some historical perspective.

<u>The Sputnik area reforms</u>. From 1955 until approximately 1971, a "Golden Age of Science Education" spawned a generation of science reforms based on discipline-specific studies, designed primarily by scientists to produce more scientists and engineers, and incorporating laboratory activities to provide first-hand experience and an understanding of the science inquiry process to students in a call for excellence in education (Blosser, 1990 & 1989; Klopfer & Champagne, 1990; Hurd, 1986; Kyle, 1985; Aldridge & Johnston, 1984; Arons, 1983).

Examples of the <u>new</u> curricula created during this period were Physical Science Study Committee (PSSC) physics, Chemical Bond Approach (CBA) and CHEM Study chemistry, and Biological Science Curriculum Study (BSCS) biology. Elementary school programs such as the Elementary Science Study (ESS), Science Curriculum Improvement Study (SCIS), Science-A Process Approach (SAPA) programs were initiated during this period as well.

The 1970s, marked by major transformations in society and culture, spawned educational reforms with particular attention to middle school science (Hurd, 1985; Kyle, 1985; Yager, 1984). The major theme in this round of educational reform was science literacy for all students (Koballa, 1985; Aldridge & Johnston, 1984; Linn, 1984; Yager, 1984; Hickman, 1984; Jackson, 1983). Psychologists and educational specialists were more often seen working along side research scientists in these endeavors, and teachers were given a more active role in the curriculum development process.

Innovations of this period included the training of "curriculum proof" teachers, action research, and the adaptation of centrally produced curricula to meet the cultural needs of a specific location. Many of the materials were marked by a modular structure instead of a single text; therefore, the content and sequence were more flexible. Teacher preparation concentrated on classroom management as well as content. Many schools introduced their own innovative

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programs during this period. Because of the many localized curricula it was difficult to "keep track" of many of the curricular changes in the schools.

Results of the reforms of the 60s and 70s. A meta-analysis of data from 105 studies compared the curricula characteristics of the pre-1955 period with the new curricula (post-1955), based on measures of achievement, attitudes, laboratory skills, critical thinking, problem-solving, creativity, logical reasoning, and skills in communicating, reading, and mathematics. This analysis and related work indicated that, based on these criteria, the new curricula had positive effects on student outcomes (Shymansky et al, 1990; Shymansky et al, 1983; Kyle et al, 1982). Despite significant increases in student performance, most of these "Golden Age" projects were abandoned because

- they were considered too difficult for most students,
- the teachers did not understand the conceptual structure of the programs, or
- the teachers could not master the inquiry or discovery style of teaching necessary to use the programs as designed (Hurd, 1986).

Extensive case studies of actual school practice indicated that teaching science as inquiry, and other aspects of the espoused actions and spirit of the reforms, were not part of common school practice (Stake & Easley, 1978). The reforms were found to be effective when used, but putting them into practice was much more difficult than anticipated. This difficulty has been attributed to several causes, to the reduction of the NSF teacher institutes and training in the sciences, the omission of educators and curriculum researchers from the development teams conceiving and developing the programs, the rejection of teacher suggestions to improve successive editions for classroom use, and the recognition of "science as inquiry" as a teaching theory not a learning theory (Duschl, 1985; Welch, 1979). While inquiry science did show positive outcomes for students when compared with the rote-based learning of other curricula, it did little to increase the meaningfulness of science learning considered important by some science education researchers to promote meaningful learning and an understanding of science (Novak & Gowin, 1984; Novak, 1977). Based on these issues, the NSF curricula and their immediate successors were found to be wanting, rather than the panacea suggested by Kyle's (1985) "Golden Age" designation.

An additional criticism of the 60s and 70s reforms is the rejection by the scientist developers of the inclusion of the history and philosophy of science in these curricula (Duschl, 1985; Welch, 1979). This was the result of several factors. One major factor was the omission of these areas of science from the first curriculum developed, PSSC Physics, which served as the model for all subsequent curricula. Only Harvard Project Physics, the last among the NSF curricula, broke with the tradition to include philosophers and historians on its development board and to use historical and philosophical approaches to the nature of science. A second significant factor was the simultaneity of the cautious evolution of the philosophy and history of science and

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the development of the NSF science curricula. The philosophers and historians may have lacked credibility with the scientists of their day.

Following this heyday of reform, a series of project and position papers identified new concerns with science education. These concerns centered around the need for science literacy among all students, rather than simply the development of a scientific elite as in the case of many of the "Golden Age" reforms. In a synthesis of several of these important critiques, Harms and Yager (1981) made several strong recommendations for changes in science education, including more attention to career education, science topics related to technology and social issues, and science with personal applications for students.

Recent reforms. In creating new reforms, recent efforts pay more attention to the integration of science knowledge and constructivist approaches to learning and teaching. The leading examples of such endeavors are Project 2061 from AAAS (Rutherford & Ahlgren, 1990) and the SS&C Project of NSTA (Aldridge, 1991). More recently, a new endeavor has been established under the National Academy of Sciences to extend such reform work and produce products somewhat analogous to the NCTM Standards in mathematics. These current reform efforts need more attention, but will be discussed in detail in a later section. Attention now is turned to the broader issue of what constitutes curriculum reform in science today as reflected in these and other reform efforts.

These current reforms are being pursued in the midst of continuing concern about the state of American science education. Students perform poorly on tests, are thought to be inadequately prepared for college, and become part of a work force said to be increasingly poorly prepared for competition in the world market place. The numerical indicators of these conditions are numerous, diverse, and often quoted. One study set the percentage of scientifically literate Americans at only 6%, based on their knowledge of the processes of science, identification of scientific concepts and terms, and their understanding of the impact of science on society. (Darling-Hammond & Hudson, 1990, p. 224) While jobs in the fields of science and engineering increased at a rate three times the national rate of employment, college enrollment in these fields declined. Scores on the science portions of the National Assessment of Educational Progress (NAEP) remain low (Mullis & Jenkins, 1988) and scores on the Second International Science Study found showed that American students did not rank highly among students from other countries (McKnight et al, 1987).

The call for Science for All. If we are looking at this situation from a perspective of giving each citizen a basic knowledge of science (scientific literacy), and not from a perspective of generating more scientists, then curriculum reform is for all students. It is generally accepted that each citizen should be literate, be able to read and write, and possess other skills necessary to function in our society. Because of the important role of science and technology in today's world, this view of literacy must be expanded to include basic knowledge and skills in the area of science. This is the primary goal of Project 2061 as stated in Science for All Americans (Rutherford and Ahlgren, 1989) and is a predominate theme among researchers and science educators reflecting on curricular reforms of the present and the past (Kyle, 1991; Hlebowitsh and Hudson, 1991; Duschl, 1988; Fensham, 1987).

> "Knowledge of science, mathematics, and technology is valuable for everyone because it makes the world more comprehensible and more interesting. Science for All Americans does not advocate however, that all students need to gain detailed knowledge of the scientific disciplines as such. Instead, the report recommends that students develop a set of cogent views of the world as illuminated by the concepts and principles of science" (Rutherford & Ahlgren, 1990, p. 7).

They go on to state that "given the great and increasing impact of science and technology on every facet of contemporary life, part of scientific literacy consists of possessing certain scientific values, attitudes, and patterns of thought" (Rutherford & Ahlgren, 1990, p. 9).

Females and minorities. While philosophically there may be a commitment to equity-based science literacy for all, recent history suggests that gender equity and equity for minorities and the physically handicapped in American science education have not been the case in practice.

> "Women and non-Asian minorities are underrepresented in the science, mathematics, and technology work force. Although women's share of the professional work force had risen to 49%, in 1986, they still constituted only 15% of the employed scientists, mathematicians, and engineers. In the same year, blacks (who constitute 10% of all employed workers and 7% of professional workers) and Hispanics (5% of all employed workers and 3% of professionals) each represented about 2% of the scientific work force. The physically disabled represented approximately 2% of scientists and engineers." (Oakes, 1990, p. 155).

According to Oakes (1990), women have made progress in the last two decades in attaining scientific preparation. Blacks and Hispanics have not demonstrated similar increases. Rates of degree attainment and participation in science-related fields remain low. Three critical factors (Oakes, 1990) have been identified as contributing to the inequality of participation in science-related careers, including:

1. the lack of opportunities for women and minorities to learn science,
2. the low achievement of these groups in science and science related subjects, and
3. the decision made by members of these subgroups not to pursue a science or science related field.

All of these factors are related to the lack of role models and encouragement for these groups, and for some minorities, the lack of an opportunity to pursue math and science because the school which serves their community does not offer such a course of study. This deficiency may be due to financial problems, lack of qualified staff, or simply lack of demand. For some members of minorities, as with women, the lack of opportunity may not be a physical barrier but a lack of encouragement to follow such a course, or the view that science is not important or of value for members of these groups. (Oakes, 1990)

To correct this situation the time for intervention is in the elementary school. By the time students reach high school most of their values, interests, and ideas are already formed (Oakes, 1990). An interest in science must be generated while children are young and receptive to new ideas; they need to gain confidence by experiencing success in science. Then it may be possible for them to see themselves in the role of a scientist.

Past curriculum reform efforts have not addressed significantly the unequal representation of women and minorities in science. Gender and minority equity are not exclusively curriculum matters. Aspects of teacher attitude, teaching style, and school culture all play a part in generating a bias free environment. But just as teacher's philosophy of what is science and how it such be taught are greatly influenced by curricular materials, equity issues are an important aspect of curricular reform.

Working with bright, liberal arts graduate students, Tobias (1990) found many students competent in science chose not to pursue science studies for several reasons related directly to the way science is taught at the university level. These reasons include a patronizing teaching style in which many professors serve as keeper of the information rather than the facilitator of student learning; the sense of competition which precludes collective problem solving, intellectual discussion, and involvement with the subject matter; the resulting a sense of isolation or lack of community; and a test focus on mathematical detail with little or no integration of concepts to illuminate the "big picture" (Tobias, 1990).

These conditions are the ones under which most of today's high school and middle school teachers were trained in college science. In addition to serving as a view of the science discipline, the university style of teaching has also served as a model of science teaching for many of the precollege science teachers. The concerns expressed by Tobias' graduate students concerning their undergraduate science classes may also be affecting students in their high school science classes. Modeling precollege science teaching after college practices may alienate a portion of the interested and talented student population, contribute to a continued exodus of students from science, and add to the myth that science is for an elite few.

What is Needed for Science Education Reform to Occur?

To implement constructivist learning and teaching as an innovation in science teaching usually requires many interventions such as provision of suitable materials, inservice training and follow-up assistance, administrative support, an assessment program compatible with constructivist learning, and a school climate and culture that encourages, values and supports change. Some of these conditions are more readily attainable than others. Most are cost effective only in combination with other interventions (Anderson, 1990). For example, inservice education of science teachers generally is effective, only if done as part of a broad-based implementation effort that includes other interventions such as improved curricular materials, instructional leadership, coaching, and revised assessment. (Anderson, 1990).

Some of these interventions are specific to science such as a materials support system (including resupply of the required expendable materials) for a hands-on elementary school science program, but most of this topic can be addressed in the same context with reforms for mathematics and higher order thinking. Thus, this topic will be addressed in more detail in a later section on bringing about reform in all of the areas at hand.

In order not to repeat the pitfalls of the past, Yager (1992) suggests that teachers and their ability to change are central to the success of current reform. "Solutions will require that teachers must:

1. Internalize goals for science teaching other than a preparatory one, that is, preparing for further study of traditional science concepts. There is a common belief that action as a result of instruction must first cone after mastery of basic concepts.

2. Be willing to abandon standard textbooks where less than 10% variation from one text to the next at a given level. Currently only 10% of the teachers are willing to abandon their basic textbooks.

3. Assist students in utilizing science concepts and processes in attacking problems that exist in their own lives and communities. Currently less than 10% of high school graduates are able to use and to act upon information and skills they are taught.

4. Assess their successes with teaching and learning beyond testing students for the degree they can repeat information or perform basic skills outside any real-world context.

5. Be involved professionally (currently only 15% are) and demand new approaches and materials (a critical mass of 25% is needed to affect the preparation and use of improved materials)." (Yager, 1992, p. 907-908)

Reform Projects Currently Under Way

With the renewed emphasis on reform in science education two major and several smaller scale curricula reform projects are presently under way. The two large projects, both national

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in scope, are Project 2061 established by AAAS, and the SS&C Project of NSTA. In addition, there are many other projects, many funded by the National Science Foundation (NSF), which have prepared materials for use in a particular part of the curriculum.

In many ways all of these reform efforts encompass much of the philosophy described earlier. They are sensitive to the necessity of science literacy for all students. They embrace the emerging views of constructivist learning. They develop the interdependency and interaction of science, technology and societal issues. Whether they fulfill their promise on these and other conceptions of a "new science education" remains to be seen.

Project 2061. This effort, which began in 1985, emphasizes scientific literacy for all students. It is presently in phase two of its several phase development plan. In phase one, the project established a conceptual base, outlining what every American should know in order to be scientific literate (Rutherford & Ahlgren, 1990).

The basic dimensions of scientific literacy as recommended by a national council of advisors to the project are:

"(1) Being familiar with the natural world and recognizing both its diversity and its unity.

(2) Understanding key concepts and principles of science.

(3) Being aware of some of the important ways in which science, mathemat ics and technology depend upon one another.

(4) Knowing that science, mathematics, and technology are human enterpris es and knowing what that implies about their strengths and limitations.

(5) Having a capacity for scientific ways of thinking.

(6) Using scientific knowledge and ways of thinking for individual and soci al purposes." (AAAS, 1989, p. 4)

In its current phase, the object of Project 2061 is to transform "what every American should know" to alternate curriculum models. "Alternate models" means that each development site will produce its own curriculum, independent of all other sites. Although all will be based on the same general principles, the curricula from different sites may be quite different. Presently, groups in six sites across the country -- San Diego, San Francisco, San Antonio, Philadelphia, and two smaller towns in Georgia and Wisconsin -- are engaged in this activity. Each site is a cooperative venture between a school district and a university. The next phase, phase three, will be to develop each model into an actual curriculum and implement it.

Besides outlining what citizens should know in order to be scientifically literate, Project 2061 also enters the realm of how they should know. A departure from the traditional structure of teaching is advocated in two ways:

"(1) The boundaries between traditional subjects should "be softened" and more emphasis placed on the connections among the science disciplines, and science, technology, and society.

"(2) The amount of detail or fact learning should be considerably less. Emphasis should be placed on ideas and thinking skills with details used as an enhancement for understanding a general idea." (AAAS, 1989, p. 5)

Although Project 2061 calls for learning fewer facts, it also suggests more emphasis on topics which are not in the traditional science curriculum. These include the nature of scientific enterprise; the relationship of science, mathematics and technology to each other and the social system; the history of science; and the major conceptual themes that are common throughout all the sciences (for example, equilibrium).

Along with the development of new curricular models, improving the teaching of science, mathematics and technology is a major step to success. Teaching should be based on learning principles that are derived "from systematic research and from well tested craft experience" (AAAS, 1989, p. 11). In keeping with the character and spirit of scientific inquiry and scientific values, teaching should begin with questions dealing with phenomena, not answers to be memorized or learned. Students should engage in the use of hypothesis, and the collection and use of evidence. The instructional activities in the classroom should include designing investigations, using the processes of science, and engaging in hands-on experiences. Student creativity and curiosity should be encouraged and rewarded, and the students should work together as a team whenever possible (AAAS, 1989).

The project is built on a commitment to science for all students with equality of opportunity for all groups. "Educational reform must be comprehensive, focusing on the learning needs of all children, covering all grades and subjects, and dealing with all components and aspects of the educational system" (AAAS, 1989, p. 11).

There is also a commitment to a process of reform that is long-term and involves the many parties who have a stake in the process. They are convinced that collaborative action is needed on many fronts; administrators, university faculty, community, business, political and labor leaders must work together with teachers, parents, and students to make reform a reality (AAAS, 1989).

Scope, sequence, and coordination. A second major science education reform project was initiated in the fall of 1989 by the NSTA with financial support from both the Department of Education and the National Science Foundation. It is founded on two premises: that good teaching should reflect cognitive and developmental theory and research, and that all four traditional science disciplines should be taught each year at the secondary level. Some of the teaching/learning principles include qualitative experience preceding quantitative measurements and hypothesis-driven activities to generate theoretical relationships in a constructivist mode. Aldridge (1991) describes the program's foundation in the following manner:

> "The various research efforts, and their successes, had clear implications for reform. Research on the spacing effect (Dempster, 1988) implied that science should be taught a few hours per week over several years instead of concentrated into one year. From the work of Bruner (1960) and others (Arons & Karplus, 1976), the sequencing is shown to be important. The Piagetian implications are that concrete experiences with science phenomena should be provided before terminology. Concepts, too, should be derived from experience, with students acquiring a concept from experience with a phenomenon in different contexts. When concepts are established, they should be symbolized and those symbols related to each other. These more complex relationships, too, would be built up over time." (pp. 2-3)

Important research considerations have been encompassed in the development of this reform movement. Important aspects include concept development from multiple context experiences, the sequencing of material so that hands-on experiences precedes terminology, the sequencing over time of increased levels of abstraction, and the challenging of student preconceptions by providing appropriate experiences (Aldridge, 1991).

> "The project is underway in California, Texas, Iowa, North Carolina and Puerto Rico. Centers are attempting to provide science every year in four subjects: chemistry, biology, and earth and space science, and to every child in grades 7-12. The middle years are integrated in some places, STS in others, and separate subjects in others. The high school years will probably be separate disciplines but with strong coordination" (Aldridge, 1991, p. 7).

Other activities. A number of smaller science education reform projects are under way as well, some of which are meant to supplement rather than replace the existing curriculum. Among them are a number of projects funded by the National Science Foundation to develop curriculum materials for elementary and middle school science. A number of these elementary school programs are now available and the middle school programs are not far behind.

Like Project 2061 and SS&C, many of these programs are still in the developmental stage. Some have field test data, while others are still on the drawing board. Essentially no research on these endeavors has yet been published in refereed sources. At this time the success of most of these programs in fulfilling the aims and philosophies they espouse rests only on internal field test studies, if that.

Examples of these varied programs include the following (Loucks-Horsley, 1989):

"The Science Connection," a supplementary program for grades 1-6, designed to take advantage of an existing vehicle, the basal textbooks now in broad use.

The Scholastic, Inc. Project "Super Science: A Mass Media Program," consisting of two classroom science magazines (one for grades 1-3, the other for grades 4-6) and a companion series of computer disk materials.

"Full Option Science System-FOSS" from the Center for Multisensory Learning of the Lawrence Hall of Science which provides a collection of multisensory, laboratory-based science activities for grades 3-6.

"The National Geographic Kids Network Project," a series of flexible elementary science units featuring cooperative experiments in which students in grades 4-6 share data nationwide using telecommunications.

"Elementary School Science and Health Materials," a complete K-6 science/health program designed and developed by the Biological Sciences Curriculum Study (BSCS).

"Science and Technology: Investigating Human Dimensions," (also from BSCS), a three-year, activity-based, middle school science and technology program for grades 5-9.

"Improving Urban Elementary Science: A Collaborative Approach," designed to improve students' ability to think critically, use language, and solve problems using the natural world as an experimental base.

"Improving Urban Middle School Science," designed for middle school science.

"Interactive Middle-Grades Science," for grades six through eight, under development by Florida State University and Houghton Mifflin Company.

"Explorations in Middle School Science," a computer-based program of 90 lessons in Life, Earth, and Physical Science intended for the special needs of middle and junior high schools.

Frameworks for science and technology education, anythesizing the educational change literature and the key elements of science content knowledge and process skills, have been drafted for elementary and middle school levels (Bybee et al, 1990 & 1989). A high school framework is presently underway. Also available are a variety of publications from the National Center for Improving Science Education, which address educational change in science education (Loucks-Horsley et al, 1990 & 1989; Raizen et al, 1989).

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In addition to these national activities, there are many local curriculum reform endeavors underway which reflect much of the same philosophy and practices described earlier. It is an activity which is encouraged by the presence of the larger national programs described above and is fostered by state level actions as well. Reform of state testing programs in states such as California and Connecticut, for example, clearly is part of the national movement toward a reformed science education in America.

One major study aligning science curriculum reform emphasizing problem solving and process with alternative assessments that can be conducted on a large scale has been reported (Baxter et al, 1992; Shavelson et al, 1991). Laboratory notebooks have been found to be nearly as reliable and valid a measurement of performance as observed performance for assessing the science process understanding of elementary students.

Research on the results is very limited, mainly because these activities have not been in existence long enough to have reached that stage. This case study research is an important next step.

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HIGHER ORDER THINKING

Driving Forces and Historical Perspective

Over the last 5 to 10 years, most national and state business and education organizations have developed one or more reports that make the argument that the education system must change to keep pace with the changes in society. Common to the majority of these reports is the theme that students must gain higher thinking abilities. One of the national education goals which grew out of the historic 1989 education summit of the president and governors, states it succinctly: "By the year 2000, ...every school in America will ensure that all students learn to use their minds well, so they may be prepared for responsible citizenship, further learning, and productive employment in our modern economy" (America 2000: An Education Strategy Sourcebook, 1991).

Numerous states are developing "common cores of learning" (e.g., Maine, Connecticut) or strategic plans (e.g., Utah) that emphasize new skills and new approaches to education needed to keep pace with the changing world conditions. The reports place varying emphases on the economic conditions, demographic shifts, changing family structures, explosion of knowledge, technological changes, shifting international political alliances, new demands of maintaining a democracy and other factors as the reasons that students must be taught higher level thinking abilities. Individually and collectively they make the argument that the education system must take on the challenge of teaching all students to achieve at higher levels on more complex concepts and understandings.

As a nation and world we are moving into an age where the use and exchange of information is dominating our economic system, the pace of change is being accelerated by continued innovation in communications and computer technology, and communication skills and literacy are key to individual and collective accomplishment (Romberg et al, 1990).

Workers must be prepared to change jobs four or five times; they must be capable of lifelong learning. The Information Age economy represents a profound switch from physical energy to brain power as its driving force.

> "Instead of training all but a few citizens so that they will be able to function smoothly in the mechanical systems of factories, adults must be able to think....This is significantly different from the concept of an intellectual elite having responsibility for innovation while workers take care of production" (Zarinnia & Romberg, 1987, pp. 23-24).

While external forces and national and state reports have been building the case for change, those within the education system, or closely aligned with it, have not been sitting idly by. Using emerging theories and perspectives about learning, psychology, and organizational design, educators and researchers have devoted great attention to how to help students learn to think in more complex ways.

There are a variety of theories about how (and if) people can learn to think, none of which is fully developed. The research on the theories and programs derived from the theories is piecemeal and often preliminary. As has been evident in looking at the themes identified under the general issues of teaching and learning, the teaching of thinking is still in the early stages of development. Much is still unknown and approaches are continuing to evolve and unfold as programs for use in the schools are put into practice. This section on thinking across the disciplines provides information on specific programs and strategies to teach thinking that are now underway. Although by no means a complete listing, it illustrates the range of approaches in operation.

Programs, Projects and Research in Progress

Given the huge number of efforts under way to determine how to teach thinking, it is not feasible to identify all of the research here. Suffice it to say, that much more has been said about teaching thinking than has been resolved. Few of the numerous methods available have been subjected to rigorous assessment and evaluation. In some cases positive results have emerged, but follow-up studies and long-term studies are uncommon (Perkins, 1987).

Given below are examples of the types of programs and projects under way. While not exhaustive, it represents the type of efforts under way. Many of these efforts have some type of research or study connected to them but they vary greatly in focus, depth, and breadth. References are provided for the interested reader to pursue further information about the status of the program or its accompanying research.

Throughout the country many reform efforts, often labeled as restructuring of the way the school operates, are under way to help students learn at higher levels. Several are based on particular research and are led by researchers, organizations, and/or practitioners who have established a network or cluster of schools that are following a certain approach to helping students develop their thinking abilities. Many other schools are engaged in redesign of their schools using an eclectic approach, drawing from the national efforts and their own experience to remodel their current approach to teaching and learning.

Three documents that describe various programs designed to teach thinking have been used as the basis for the following list. These documents provide further information. The programs and projects will be grouped according to the document in which they are referenced.

In "The Teaching of Thinking," Nickerson, Perkins and Smith (1985) describe programs grouped into five categories depending on the predominant approach they are using. They emphasize that the programs often combine approaches and this categorization should not be taken as rigid differences among the program. The five categories and names of the programs they describe are:

Cognitive operations approaches: The Instrumental Enrichment Program, The Structure of Intellect Program, Science...A Process Approach, ThinkAbout, BASICS, and Project Intelligence.

Heuristics-oriented approaches: Patterns of Problem-Solving, Schoenfeld's Hueristic Instruction in Mathematical Problem Solving, A Practicum of Thinking, The Cognitive Studies Project, The Productive Thinking Program, Lateral Thinking, and the CoRT Program.

Formal thinking approaches: ADAPT (Accent on the Development of Abstract Processes of Thought), DOORS (Development of Operational Reasoning Skills), COMPAS (Consortium for Operating and Managing Programs for the Advancement of Skills), SOAR (Stress on Analytical Reasoning), and DORIS (Development of Reasoning in Science).

Thinking through language and symbol manipulation: Language in Thought and Action, Writing as an Occasion for Thinking, Writing as a Means of Thinking, Universe of Discourse, Modeling Inner Speech and Self Instruction as a Means of Teaching Thinking, and LOGO and Procedural Thinking.

Thinking about thinking: The Philosophy for Children Program, The Anatomy of Argument, Metacognitive Skills, and The Complete Problem Solver.

In their summary comments about the programs, Nickerson, Perkins and Smith (1985) say:

> "[I]t is not necessary to have a perfect program in order to teach something of value. Most, perhaps all, of the programs we have reviewed are capable, in the hands of skilled teachers, of enhancing some aspects of thinking. That is not to suggest that there are no differences in quality or effectiveness among the programs we have reviewed. But perhaps (almost) any program is better than none, independently of the specific techniques that are used. Indeed it may be that among the things that any program might do, nothing is quite as important as simply getting teachers and students focused on thinking processes ar ' genuinely interested in attempting to improve them." (p. 345)

In 1986, Paul Chance provided a survey of programs designed to teach thinking in the classroom. He reviewed the following programs: CoRT Thinking Lessons, Productive Thinking Program, Philosophy for Children, Odyssey, Instrumental Enrichment, Problem Solving and Comprehension, Techniques of Learning and Thoughtful Teaching. He encourages interested parties to review the materials in depth as well as to take advantage of articles in publications such as Educational Leadership and Phi Delta Kappan and in two newsletters -- Teaching Thinking and Problem Solving and Human Intelligence.

Chance (1986) found that the programs he reviewed were alike in building on the following assumptions or beliefs:

1. Thinking is a skill and can be taught.

2. Thinking is best taught by direct and systematic instruction.

3. The emphasis of instruction in thinking should be upon the process of thinking, not its products.

4. Students must use the thinking skills they are to learn.

5. Teachers should reinforce the appropriate use of thinking skills.

6. Teachers should make allowances for individual and developmental differences among students.

7. Thinking should be taught in a relaxed, nonthreatening atmosphere.

8. Thinking must be taught over a period of years.

9. An effort must be made to see that the skills taught in the program carry over to other subjects.

10. The teacher is the single most important determinant of the success of a thinking program.

The third document, "Restructuring the Education System: A Consumer's Guide, Volume I" (ECS, 1991), identifies programs that are operating nationally that focus on not only the teaching of thinking but the broader changes that need to go on in the school, community, and/or education system. A brief description of each is given simply to illustrate how they are moving beyond the specific classroom focus in many cases, to a broader change agenda. No literature was found that contrasted the specific programs listed above with the programs below that have a broader focus. Considerable research and study is yet needed to better understand this burgeoning field.

Coalition of Essential Schools and Re:Learning -- The Coalition of Essential Schools (CES) was established by Theodore Sizer at Brown University in 1984 based on his 4-year study of high schools as reported in **Horace's Compromise**. Nine common principles guide the work of schools that are involved. In 1988 the Education Commission of the States joined forces with CES and several states to create Re:Learning. Through this partnership CES works directly with

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schools while ECS works with policymakers and administrators at district and state levels to create a supportive climate for the school changes. The overall goal of both CES and Re:Learning is to help all students learn to use their minds well. Some research is underway with more being planned. Preliminary results from a few schools and some ethnographic studies indicate that students are learning more and teachers are supportive of the effort.

Foxfire -- Foxfire began in 1966 when a high school teacher, Eliot Wigginton, tried a new approach to stimulating his students' interest in language and learning. The students produce a quarterly magazine, **Foxfire**, for and about their community in Georgia. Over subsequent years about 200 student magazines, modeled on Foxfire, sprang up across the country. Now there are five Teacher Outreach Centers to train teachers in the Foxfire approach and eleven teacher networks across the country.

Mastery in Learning Consortium -- The National Education Association's Center for Innovation began the Mastery In Learning Consortium in 1990 to help school communities transform their schools in terms of teaching, learning, curriculum, and the interrelations of these to best fit their school. The participating schools are interconnected by a computerized network and database.

Montessori in the Public Schools -- Around 1900, the Montessori method was developed in Italy for retarded and impoverished children. The model soon spread throughout Europe and North America as an alternative mode of education. The approach is based on the belief that human intelligence is greatly influenced by environment rather than being fixed from birth and that children have a spontaneous interest in learning. The Montessori Public School Consortium was established in 1988 at Cleveland State University.

The Paideia Program -- The 1982 publication, The Paideia Proposal: An Educational Manifesto by Mortimer Adler serves as the basis of the Paideia Program. The program is based on the beliefs that universal, quality education is essential to democracy, schooling should prepare students to be lifelong learners, and tracking is harmful and discriminatory. Paideia principles have been adopted in over 200 schools nationwide.

School Development Program -- The School Development Program began as a collaborative effort between the New Haven School System and the Yale Child Study Center in 1968. The program emphasizes a climate of trust, cooperation, and caring among teachers, students, parents, and the community and having students experience concepts to best understand them. The program is based on the belief that the sources of most learning and behavior problems are conflicts of class, race, income, and culture between children's home and school environments rather than children themselves.

Accelerated Schools Project -- The Accelerated Schools model developed out of a Stanford University research project in the early 1980s focused on at-risk students. The project operates on the belief that all children can learn and schools should accelerate, not remediate,

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students. The project takes the position that at-risk students should be taught the way gifted and talented students are taught.

Success for All -- The Success for All Program grew out of a partnership between The Johns Hopkins University and the Baltimore City Public Schools. It operates on the belief that every child can learn, and success in early grades is critical for future success in school. It emphasizes comprehensive and intensive teaching.

Whole Language -- Whole Language is a broadly defined curriculum reform movement that combines ideas gained from research in linguistics, cognition, language acquisition, child development, reading, writing, and other related areas over several decades. The name relates to the principle that children learn oral language quickly and instinctively, without having it broken up into isolated or abstract bits and pieces as is commonly done in basal readers and grammar books. The movement is largely a grassroots one among teachers.

These examples of programs and initiatives to help students learn to think span a wide range of perspectives and illustrate the fact that many strategies and starting points are being used to teach thinking. Considerable work remains to be done both in designing approaches and conducting research.

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THE PROCESS OF REFORM

Curricular reform is a complex, multidimensional process, requiring care and planning to execute. If these planned innovations are to be sustained, substantial thought, effort, and skill must be exercised from the initial conceptions of the change to the point where the change is an integral and ongoing fact of school life. Understanding what research says about such a process is the focus of this chapter.

Understanding the reform process at a given time and place -- whatever its particular form and degree of success -- requires a systemic outlook. Many different actions may be part of the process in a particular instance, but an understanding of each of these separate actions by themselves is insufficient. All of them together may not work if initiated without consideration for their synergy. Understanding the situation systemicly requires attention to psychological, philosophical, sociocultural, and subject-matter perspectives (Anderson, 1992). It requires attention to organizational and political considerations. Actions taken at the national, state, district, school, and classroom levels, for example, can interact to support change in a common direction, or they can counteract each other in such a manner that change is defeated. And even though all actions taken are complementary, there is the possibility that the omission of some particular action or actions could stall what would otherwise be a successful reform effort. A vision of what should be must be combined with a systemic process of working toward that vision.

The importance of this systemic perspective gradually is gaining recognition. In his widely recognized book on educational change, Fullan (1982; with Steigelbauer, 1991) notes the importance of this systemic perspective although all of its implications have not been developed in the sense described above. Anderson (1990, 1984) has found a systemic approach essential in a cost-effectiveness analysis of some 69 actions proposed for the improvement of science and mathematics education. A theoretical framework for the interpretation of the cost-effectiveness, built from a review of the then extant literature on educational change, effective schools and principals' leadership, presents the probable costs and effectiveness of the 69 different individual interventions. But the study concludes that the only meaningful way to consider these actions is in various systemic combinations that included federal, state, district and school level initiatives. No one -- or even two or three -- change endeavors --such as an inservice education program, or a new set of curricular materials, or peer coaching -- is likely to produce the substantial curriculum reform of the magnitude desired in the areas of mathematics, science and thinking skills. Reform endeavors must be systemic.

Organizational theory and research, almost entirely conducted in nonschool contexts, also speaks directly to the importance of a systemic outlook (e.g., Banathy, 1991; Senge, 1990). This theory provides a basis for developing specific approaches at all levels that together will increase the probability of successful reform. The entire chapter on the change process which follows is based on the premise that systems thinking is essential for conceptualizing change endeavors and research on them.

To a large extent this chapter on the process of change is based on the work of other reviewers. The most complete review of the extant educational change literature and its myriad complexities is the second edition of Michael Fullan's The New Meaning of Educational Change written with Suzanne Stiegelbauer in 1991. Because of its recency and completeness, this scholarly review of the literature will be the central source of what follows, although it will be supplemented by other research that further elucidates some specific aspects of curricular reform. For our purposes it also is necessary to extend this review to include a more substantial consideration of systems thinking. To do so, attention is turned to the literature on organizational theory, especially the popular work by Senge (1990).

The Barriers to Making Changes

As a beginning point to this review it is well to consider again the many barriers to the desired changes in mathematics, science, and higher order thinking. With a task as massive as changing multiple aspects of the education system, it is small wonder that there are many barriers to its success. The following ones tend to dominate the research:

1. Reformers do not all agree on the type of reform and the strategies for reform. The reforms which followed the publication of A Nation at Risk were focused on the regulatory parts of school renewal (Boyer, 1988). "Simplification, prescription, and performance measurement were the policy mechanisms that were most common to Wave I reforms. Those who believed that schools' problems could be traced to low standards for students and teachers and a lack of focus on academic achievement felt these strategies were sensible" (Hawley, 1988, p. 419). A key assumption underlying state statutes from 1983 to 1987 was that the existing system could be intensified to meet the challenge (Kirst, 1988). Such assumptions interfere with current reform efforts. "Believing that more fundamental reforms are needed, one might conclude that these prescriptions call for more of what made the patient ill in the first place" (Goodlad, 1986, p. 425).

2. Many teachers are not prepared to teach using the strategies proposed by the new models of instruction. For example, Schoenfeld (1990) indicates that conceptions of "how to teach for mathematical thinking have of necessity lagged behind our evolving conception of what it is to think mathematically" (p. 88). Burkhardt (1988) notes that teaching problem solving in mathematics is harder for the teacher in at least three ways:

> "mathematically - the teacher must perceive the implications of the students' different approaches, whether they may be fruitful and, if not, what might make them so.
>
> pedagogically - the teacher must decide when to intervene, and what suggestions will help the students while leaving the solution essentially in their hands, and carry this through for each student, or group of students, in the class.

personally - the teacher will often be in the position, unusual for mathematics teacher and uncomfortable for many, of not knowing; to work well without knowing all the answers requires experience, confidence and self-awareness" (Burkhardt, 1988, p. 18).

As the coach, the teacher must play an active role in monitoring both process, as an active diagnostician, and product. Greater demands will also be made on subject matter knowledge as the teacher is expected to pose problems which transcend traditional subject matter barriers. Many teacher will also need help in determining new strategies for classroom management (Knapp et al, 1991).

3. Many teachers hold beliefs and priorities that are incompatible with the envisioned changes. First, some teachers hold lower expectations for some students, believing that only a few students can learn a great deal (Oakes & Lipton, 1990; Foster, 1989; Levin, 1987). Teachers' views of subject matter are also problematic. For example, many view mathematics as memorizing procedures and formulas for doing exercises rather than seeking solutions, exploring patterns and formulating conjectures (National Research Council, 1989). Even the language used to communicate new goals can make implementation difficult. Problem solving has had multiple, sometimes contradictory meanings. Schoenfeld (cited in Schoenfeld, 1990) conducted a survey of college mathematics departments and found problem solving may be defined as the solution of routine exercises or may require mathematical engagement to solve perplexing questions.

4. Community members and parents hold beliefs and priorities that interfere with the change. Goodlad (1986) says that the expectations for the schools increased as knowledge which could not be gained through direct experience grew.

> "By 1980, all of the 50 states set for the schools not just academic but social, vocational and personal goals as well -- and parents wanted them all. So many and varied were the schools' efforts to meet them that the curriculum of the secondary level, in particular, resembled the wares displayed in a shopping mall" (p. 424).

Parents in the U. S. are more likely to attribute success in mathematics to innate ability, while the Japanese are more likely to attribute success to effort (Stigler & Perry, 1989, cited in Schoenfeld, 1990). Likewise, in the United States understanding is equivalent to sudden insight, while in Japan understanding is achieved gradually through struggle.

5. Administrators and policymakers hold beliefs and priorities that interfere with the change. It should be recognized that the processes of selecting and educating administrators often are centered more on control rather than on facilitation of learning.

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6. Students have developed expectations about the nature of learning that interfere with their ability to be full participants in new models of learning. Enlarging on Lampert's work (1990), Schoenfeld (1990) identifies the following typical student beliefs about the nature of mathematics:

"— Mathematics problems have one and only one right answer.

— There is only one correct way to solve any mathematics problem -- usually the rule the teacher has most recently demonstrated to the class.

— Ordinary students cannot expect to understand mathematics; they expect simply to memorize it, and apply what they have learned mechanically and without understanding.

— Mathematics is a solitary activity, done by individuals in isolation.

— Students who have understood the mathematics they have studied will be able to solve any assigned problem in five minutes or less.

— The mathematics learned in school has little or nothing to do with the real world.

— Formal proof is irrelevant to processes of discovery or invention." (p. 69)

These beliefs have been shaped in large part by student experiences in traditional classrooms. A similar list could be compiled for science students as well.

7. New instructional, curricular, and assessment materials are needed to support the changes in the learning environment. The great majority of extant materials are not based on a constructivist approach to learning or other characteristics of the desired forms of education attributed to the reformers above. This lack is evident in many arenas.

> "A critical theoretical assumption underlying much of the curriculum and instruction provided to educationally disadvantaged students is that academic skills are hierarchical in nature...This assumption about a skills hierarchy pervades the instructional and testing materials available to educators. Anyone attempting to implement an alternative instructional approach incorporating advanced skills throughout the curriculum must be prepared to face the barrier of a scarcity of compatible textbooks." (Means & Knapp, 1991, pp. 4-5)

Assessment tools that provide diagnostic and evaluative information are needed. Presseisen (1987) describes the testing that is part of the new thinking curriculum as, "designed to help figure out concepts that students don't understand, to locate the sources of misconception, and to relate as closely as possible to the content of the subject matter and to the processes associated with learning it" (p. 6).

8. There is a lack of resources for the heavy investment needed for teacher development and other aspects of change. At a time of reduction in financial support for education in most areas of the country, the budgetary demands of curriculum reform become more prominent. Although reformed approaches to education do not necessarily cost more, the short-term costs of getting to the new status seldom are inconsequential.

9. High learning outcomes and expectations for all students are missing. The new approaches to education require appropriate levels of expectations for students; without them student performance will suffer. In their description of principles to apply in the design of outcome-based education, Spady and Marshall (1991) promote the following actions:

"— Ensure clarity of focus on outcomes of significance.

— Design down from ultimate outcomes.

— Emphasize high expectations for success from all.

— Provide expanded opportunity and support for learning success." (p. 70)

10. The dilemmas of operating within the old education system and trying to move to a new one are pulling people in opposite directions. The problems of maintaining the old approaches while going through the often time-consuming process of establishing the new ones are substantial. Such transitions take time; learning the new often is slow; maintaining the old until the new is functioning is frustrating.

11. Systemic thinking is often missing. Systems thinking as described by such theorists as Senge and Banathy is essential but often missing. Systems thinking is of fundamental importance but uncommon in practice.

12. Inadequate attention is given to cultural differences and their nplication for how this change is handled. Bryson and Scardamalia (1991) suggest that our notion of what counts as literacy may need to be expanded. "We need to question and to deconstruct the kinds of arbitrary constraints that historically have tended to exclude minority students from effectively participating in school-based activities" (Bryson & Sasdamalio, 1991, p. 159). Serious attention should be given to the criticism of Delpit (1988) who argues,

> "The dilemma is not really in the debate over instructional methodology, but rather in communication across cultures and in addressing the more fundamental issue of power, of whose voice gets to be heard in determining what is best for

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poor children and children of color. Will black teachers and parents continue to be silenced by the very forces that claim to 'give voice' to our children?" (p. 296)

13. Mixed signals are given to teachers and students via mismatches among learning outcomes, assessment, and curriculum. The lack of alignment of testing programs, curriculum frameworks, teaching materials, and other indicators of instructional goals and strategies is substantial. This lack of alignment causes confusion, saps the initiative to move ahead with reform, and reduces the chances of coordinated approaches to reform.

14. There are structural constraints. Teachers are isolated in their work setting; they spend the majority of their working day in the company of students and cut off from their colleagues. Lortie (1975) says that due to their isolation, teachers must identify problems, consider alternative solutions, select a solution, act, and assess the outcome without the aid of colleagues. He goes on to explain how restricted opportunities for feedback account for the lack of a shared technical vocabulary which in turn limits the ability of beginning teachers to share in a preexisting body of practical knowledge and thus increases isolation.

As a widespread characteristic of life in school, isolation restricts opportunities for professional growth by forming a barrier to reform. Flinders (1988) explains that teacher isolation may be viewed as a condition of work or a psychological state. When the teachers' work day is defined by large classes and limited support, isolation may be viewed as an effective strategy for conserving energy. Many approaches to reform have encouraged the greater collaboration of teachers. Flinder's study suggests that unless such reform is accompanied by corresponding levels of support or reduction in other duties, it may serve to increase demands on teachers rather than providing the intended assistance.

Elements of the Change Process

The many substantial barriers to reform must be addressed in the process of seeking change. While it is best not to look for specific actions to match each barrier, they must all be addressed in the overall process. The particular configuration of actions will vary from one setting to another, but successful endeavors will be multifaceted, systemic, and take account of many dimensions. Many of them are described in the multilayered picture below.

Systemic change is best accomplished with the combined efforts of many players at many levels of the educational hierarchy. For innovation or change to be anything more than superficial, many questions need to be asked and answered before a change process begins. These questions entail a close look at the change to be implemented, the reasons for the implementation, and the outcomes expected from the change. Imbedded in these questions are who will be responsible for the change, how the change agents will be supported, and what materials, teaching approaches, and beliefs will be involved in the change.

Basic Considerations

Among these basic considerations needing major attention are the impact of participation in a reform effort, a clarification of the impact of the change on participants, and the nature and concerns of holistic reform.

Participation. In planning change, relevance, readiness, and resources are key elements. Relevance addresses the practicality of and the need for the innovation. Readiness focuses on the capacity of and need for the individuals and organizations involved in the innovation to change. Resources addresses the availability and provision of support for the initiation of the innovation. Resources extend beyond funding to the network of people, materials, and ideas that need to undergird the change process.

One of the resources in the change process is access to change information which is predicated on accessibility to other people with information and is differentially available to various parties in the change process. The isolation of teachers in classrooms and their limited time and energy to track down innovations and follow through on leads to new programs puts them at a disadvantage compared to administrators in gaining access to the latest and most exciting new ideas available in the outside world and in providing necessary follow-up in their advocacy of innovations. School improvement more often occurs when teachers work together and frequently discuss teaching practice, and when teachers and administrators developed a "shared language" for teaching strategies and needs. They "planned, designed and evaluated teaching materials and practices together" (Little as cited in Fullan and Stiegelbauer, 1991, p. 55).

Participation of the community in the change process can manifest itself in one of three types of involvement -- opposition, pressure, or passive support/apathy. Pressure is commonly associated with demographic changes in a district, resulting in new student populations not served by the status quo and is commonly dealt with by administrators and school boards using conflict avoidance. While more highly educated communities are more likely to exert pressure on education for high-quality academically-oriented changes, it is easier to mobilize less well educated communities to resist perceived threats.

> **"In relatively stable or continuous communities there is a tendency for innovations favoring the least advantaged not be proposed (the bias of neglect) and there is a greater likelihood that educators can introduce innovations (which they believe in) unbeknownst to the community"** (author's emphasis) (Fullan & Stiegelbauer, 1991, p. 58).

Legislation at the federal and state levels can initiate innovation. The specificity of the policies can result in a wide variety of change responses. Policies that are ambiguous and general can lead to adoption in principle only, while prescriptive policies can meet with resistance or implementation in name only. As seen in several states, policy mandates frequently caused a dilemma by using a top-down initiative to achieve bottom-up change. School district response to such external policy changes can demonstrate an opportunistic (bureaucratic) or problem-solving orientation (Berman & McLaughlin in Fullan & Stiegelbauer, 1991, p. 59). Bureaucratic districts view external funds or policies as an opportunity to obtain extra funds, while problem-solving districts look to such funding or policy changes as opportunities to solve local problems.

Participants' strength of commitment to the program is proportional to the planning of the implementation phase, and to the transformations of the process as the program is put into place. Fullan and Stiegelbauer (1991) say it well:

> "The more the planners are committed to a particular change, the less effective they will be in getting others to implement if their commitment represents an unyielding or impatient stance in the face of ineluctable problems of implementation. Commitment to a particular program makes it less likely that the planners will set up the necessary time-consuming procedures for implementation, and less likely that they will be open to the transformation of their cherished program and tolerant of the delays that will inevitably occur when other people begin to work with it." (p. 100)

Even with unsolvable problems, success is possible. Commitment concerns can be eliminated with sensitivity to other viewpoints, establishment of a process to utilize and generate ideas en route, and recognition of the limitations of planning. Basic components of initiating and coping with change include the following:

1. An understanding of the process of change, including the identification of individual roles in the process and the influence of those factors within the sphere of each role.

2. An assessment of the change in terms of the need the change addresses, the priority of that need in comparison with other needs in the system, the desirability of the vision the need represents, and the adequacy of the resources for implementation of the change.

3. A plan limiting the number of innovations implemented at a time, recognizing the developmental nature of change, and improving the chances of success long term by establishing a culture of change first and specific innovations second.

4. A process of clarification and transformation, over time, that addresses the conflict and disagreement inherent in successful change.

5. A process for integrating and synthesizing external factors affecting the change with the internal organizational conditions evolving over the course of the change that further elucidate some specific concerns of curricular reform.

Clarification of meaning. An initial step in the change process is clarification. To clarify the meaning and purpose of change requires the identification and understanding of the change to be initiated, the impact of that change on individual thinking and on educational meaning, and the understanding of the implications of the subjective and objective realities of the change.

Real change alters fundamental ways in which organizations are structured and the roles adults and children play in organizations. Real change is a serious personal and collective transformation from ambivalence and uncertainty to feelings of accomplishment, mastery, and professional growth. Real change derives from a shared meaning of change generated by the individuals experiencing the change.

This requires sufficient time, reflection, support and discussion of the change to develop a shared meaning for the innovation. A useful index of the magnitude of the resistance to an innovation is the amount of time required by the individuals to learn their new roles or skills. The more time the new role takes to learn, the more resistant individuals will be to accept or try the innovation.

The educational meaning of change is tied to the combination and interaction of the materials and resources that comprise the innovation, the teaching approaches and methods that utilize the materials and resources, and the beliefs of everyone involved in the innovation. As people and materials interact in the change process, deeply held beliefs and practices are challenged. The interface of these interactions involves more than just teachers and students. Material developers, parents, administrators, and policymakers are also stake holders in the process.

Mechanisms to address the ongoing problem of the meaning of change are necessary throughout the change process, because change occurs at the individual level, where feelings of doubt or awkwardness can accompany learning a new skill or developing new conceptions. As change is further facilitated by collective responses to it, it is often necessary to provide individuals with organizational changes. Shared meaning or "interactive professionalism" (Fullan and Steigelbauer, 1991, p. 46) supports individual and collective change.

Holistic change. "Innovations have become more holistic in scope as reformers have realized that introducing single curriculum changes amounts to tinkering" (Fullan & Stiegelbauer, 1991, p. 80). This broad-based approach to reform is powered by six themes: vision building, evolutionary planning, initiative taking and empowerment, staff development and resource assistance, monitoring and problem coping, and restructuring.

Vision building provides the values, purpose, and integrity for the how and why of improvement. It is a sharable, interactive process composed of what the school should look like and how the process should unfold. Vision building requires a core of good people to synthesize and articulate an evolving view of the vision, to experience directly the elements of change, and to increase the number of people involved in the change through communication. This core builds credibility for the vision via public dialogue and shared symbology, while legitimating emerging

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viewpoints, and implementing partial solutions as building blocks to their goal. This core group is aware of shifts in the change process affecting the organization and modify the process accordingly. They broaden political support for the change and dampen opposition as the process evolves.

Evolutionary planning is a course correcting technique to maintain an alignment between the change being implemented and the unique conditions of the school implementing the change. It provides an opportunity to take advantage of unexpected developments and better blend top-down and bottom-up participation.

Power sharing, or *empowerment* is a crucial factor in implementation. Successful leadership of implementation requires giving up power without losing control, taking active initiative without shutting out others. It is the support without being patronizing and the extension of involvement to a ever widening circle of participants and clients. It is development of collaborative work cultures, the reduction of professional isolation, and encouragement for sharing successful practices. "Constant communication and joint work provide the continuous pressure and support for getting things done." (Fullan & Stiegelbauer, 1991, p. 84).

Educational change for both teachers and students is typified by learning new ways of thinking and doing, and by developing new skills, knowledge, and attitudes. As such, educational change is furthered by *staff development* as well as by resource assistance. Teachers need ongoing interaction with the materials and methods that constitute the change implemented. While it is possible to train teachers as staff developers, for the short run teachers need direct, practical, concrete outside help. Inservice is most effective when it is concrete and occurs in the early stages of implementation. Regular meetings with peers and specialists can provide the necessary support teachers need to implement the innovation.

Monitoring is more than measuring outcomes. It is a process of gathering information as well as problem-coping and problem-solving. Monitoring makes information available for review and scrutiny. Implementation progress monitored by data collection can lead to in-course corrections that increase the probability of success. The interweaving of accountability and improvement is effective, when used as an integral part of the implementation process.

The sociological organization of the workplace may require *restructuring* to facilitate improvements and support implementation. Time for individual and team planning, mentoring and coaching roles for and with fellow teachers, new staff development policies explicitly designed to foster support and to press for improvement of the school culture, and joint teaching arrangements are several modifications that seem to be promising in facilitating and supporting change.

Stages of Change

The change process consists of three broad phases: initiation, initial use or implementation, and continuation. It is complicated by several factors, the nonlinear and multidirectional nature of the process, the scope of the change, and the total time perspective. The direction of the change (usually top-down and bottom-up simultaneously) and the scope of the change raise questions about who develops and initiates the change and who is responsible for delineating next steps. District-scale changes and classroom level changes have different dynamics and raise different concerns about roles and outcomes. The time perspective can not be precisely estimated in advance, because it should be reactive to the needs of each phase of the process. Assessments are useful to assist the identification of time needs as growth in the process occurs.

Initiation. Successful initiations of innovations have three commonalities: strong advocacy, an active initiation process, and a clear model for proceeding. Advocates for the innovation can play a very powerful role in the change process. The higher the hierarchical level of the advocate, the closer to the locus of decision making, the more effective or powerful the advocate can be in initiating the change process.

Initiation of change begins with an investigation of what really needs improving followed by an investigation of quality innovations to fit the identified needs (Orlich, 1989). Questions about the meaning and purpose of the innovation must be clearly delineated and understood by the initiators early in the process. The innovation must provide substantive advantages to students and/or teachers.

Often questions can not be fully answered until the implementation phase, particularly if the innovations has not been implemented elsewhere or if no research data are available on other implementations or the piloting of these programs. The National Diffusion Network sponsors a catalogue of validated innovations considered to be of proven quality. In this case, quality is defined as those programs "shown to cause positive observable change" (Fullan and Stiegelbauer, 1991, p. 52).

Implementation. At the point when the decision to change has been made, implementation begins. The actual process is a myriad of simple-complex contradictions. Implementation is simple in vision, but complex in enacting belief and method changes. It requires strong leadership and participation by a person with the vision for and the understanding of how to create the change. This change agent must know where to push and where to dig in to help, balancing times during which the players must find their own way with times during which he or she tightly controls the process with rigid demands. Implementation requires a fidelity to the vision with room for adaptability to bring everyone on board and move toward the goal. It needs evaluation as a measure of its forward progress but the process needs to be nonevaluative to encourage participants in their growth. Sufficient time must be allowed between the initiation and implementation phases of a change to practically review the choice with all the personnel involved or to research concerns raised in the initiation phase. "With particular

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changes, especially complex ones, one must struggle through ambivalence before one is sure that the new vision is workable and right (or unworkable and wrong)" (Fullan & Stiegelbauer, 1991, p. 73).

Successful implementation rests on the cultivation of organizational conditions and on the use of broad-based approaches. The cultivation of organization conditions occurs on many levels within the district and the school. School boards and communities are most effective in implementing change by actively working together with district level administrators toward a shared vision. A school board's primary task in planning and implementing change is to provide political stability in the community concerning the vision of the change.

Teachers and principals are the primary change agents within the district and the school. It is at the school and classroom level that change is implemented and translated into the vision expressed at other levels of the hierarchy. Successful projects need the active support of the principal, as witnessed by his or her willingness to participate. One form of participation is attendance at training workshops, a forum in which the principal can develop an understanding of teacher concerns with the program and its implementation. Principals shape the organizational conditions necessary for the success of the implementations, through multiple building level decisions about time, money and personnel. Frequently a principals' academic and practical training leaves him/her psychologically and sociologically unprepared to manage change.

The requisite factors of individual teacher characteristics and collegiality define the role of teachers in the change process. The malleability of these two forces depend on the culture and climate of the school. While it will be the actions of individuals that bring about the implementation, it is peer relationships that validate the change by deriving new meanings, creating new behaviors, and expounding new beliefs. This new shared vision results from exchanging ideas, support, and positive feelings about work, rather than from functioning in isolation from one's colleagues.

The primary external factor in the implementation process is governmental agencies which produce legislation or new policies that require implementation at the local level. The likelihood of implementation of these top-down policies is a function of the congruence between the reforms themselves and local needs, and between the method of reform introduction and the follow-through of review or enforcement demonstrated by the governmental body. The more clearly the policy maker understands the practitioner's needs regarding a particular intervention, the more appropriately the policy will be designed. To improve implementation of governmental policies, governmental agencies have begun to fund the establishment of implementation units providing technical assistance with implementation problems, the assessment of the quality of potential changes, the support of staff development, and the monitoring of policy implementation. Timar and Kirp (1989) warn that school reform efforts that ignore the complexities of the policy environment frequently fail.

Continuation. The continuation of an innovation is another in a string of decisions. Reasons for discontinuation are influenced by implementation concerns and problems. Two common reasons to discontinue an innovation are lack of funding or lack of support. It is also possible for an innovation to be discontinued in policy but continued in practice.

Continuation occurs when the innovation has become an integral part of the structure of the school or classroom; when there is a critical mass of teachers and administrators committed to the change; when procedures for continued assistance have become established as policy or guidelines; and when support is available, even to the level of an orientation process and inservice for new members.

Recognize that the term used has been continuation of change rather than institutionalization of change. This deliberate usage reflects a particular perspective, in which the improvement of educational practice becomes a continuous process leading to a long-term capacity for continuous renewal, due to a deep cultural change in the institution, rather than change arriving at a punctuated end point.

Many, even most, attempts at educational change fail. The failure is less often due to technical or mechanical problems than to faulty assumptions by planners, and inherently unsolvable problems. In trying to adapt to the multiple realities of all the participants in the change process, planners often overly rationalize the nonrational social system in which change occurs.

Changes in Behavior and Beliefs

Systemic change is best accomplished with the combined efforts of many players at many levels of the educational hierarchy. As a result, careful attention must be given to the roles of the people involved. It is the behavior and beliefs of these primary players that solidifies or undermines the change process.

Like the process of systemic reform itself, the roles of the participants in systemic reform are complex and interactive. Additionally there are several layers of participation, beginning with those closest to the change, the students, teachers and principals, to those further removed -- temporally or physically -- from the direct consequences of the change, for example, policymakers at the state and federal levels.

Again, the most complete review of the roles of participants in systemic change is The New Meaning of Educational Change by Fullan and Stiegelbauer (1991). Their view will be supplemented by additional resources on pertinent topics. The focus in this section will be on the roles each group plays in the change process, including how the groups are impacted by and impact the change, and how they interact with groups at other levels of the change. The process can begin at any or all levels, separately or in combination. The key point is to refocus the innovation initiation and implementation process from the level of the promotor to the level of the translator, or primary change agent, usually the teacher.

The inner circle of change participants is formed by students, teachers, and principals. These groups are most directly and intimately associated with the change; it is their beliefs and attitudes that impinge most directly on the change and the change process. The focus here is on the interaction of these people with the change. It must be remembered that who these people are, and what they believe, interacts with the process of change. In some instances it may be useful for the reader to review Fullan and Stiegelbauer (1991) for a complete treatment of the social conditions and mental frameworks from which these groups are operating.

Teachers

Classrooms and schools are effective when quality people are recruited to teach, and when the work place is organized to stimulate and reward accomplishments. Consequently teachers look at three criteria in assessing change, the need for the change (both explicit and implicit), the procedural clarity of the change process, and the personal cost-benefit ratio of implementing the change. Teachers are governed by practicality in their review of an innovation; therefore, practical considerations need to be addressed early in the initiation process. The need for change is defined by the following teacher consideration:

1. the specific need the change addresses;
2. how the change affects student interest and learning;
3. existing evidence that the change does in fact work;
4. the congruence of the innovation with teacher estimation of student reaction to the change; and
5. the fit of the innovation with the teacher's situation.

Procedural clarity, or what the teacher will need to do to implement the change, requires the operationalizing of the meaning of the change. Specifically, teachers are concerned with what changes in teaching methods, in assessment procedures, in classroom management are necessary and how short the timeline for mastery of new ideas and skills is. The more change in the operational meaning of teaching, the more beliefs of teachers need to be addressed to enact the innovation. The results of other teachers' experiences with the innovation are significant here, and carry a great deal of consideration.

Personal cost-benefit ratio is a two-part criterion. First, teachers are concerned with how the change will effect them personally. This concern is viewed in terms of the amount of time and energy the teacher will need to expend to affect the desired change balanced against the personal excitement the innovation engenders in the teacher, and the new skills the teacher will need to develop to competently introduce and utilize the program with students. The difficulty of learning new skills and unlearning old ones is vastly underestimated, especially when teachers are satisfied with their current program. Teachers pragmatically look at how the innovation ranks among and meshes with the existing priorities to which they have already committed.

The second aspect of the personal cost-benefit criterion involves teacher interaction. The isolated nature of teaching as a profession makes this a critical issue. Teachers are concerned with not only the rewards of interacting with peers and others in terms of change, but also with the roles they will need to play in the interaction process. The degree to which teachers are likely to change is proportional to the amount of technical assistance and personal interaction in which they participate as part of the implementation process. Collaboration assists teacher learning, helps to generate teacher certainty to maintain teacher competency, and bolsters teacher commitment to the innovation.

As inservice education is the most common and simplest format for promoting teacher collaboration and collegiality in the service of change, inservice programs should move from the concrete to the abstract, addressing teacher concerns with practical procedures and activities first, and then discussing underlying principles. Collegiality runs amuck of the isolation culture when time and energy are being drained from meeting immediate instructional demands.

Principals

If the starting point of change is with ourselves, principals must reflect on their own conceptions of their role without placing unnecessary limitations on what can be done. To improve their ability to facilitate change, principals need to reflect on four attributes: knowledge and conceptions about change, knowledge or familiarity with the content of change planning, communication skills, and interpersonal skills. They will use and test each of these as they proceed through the change process with their staff.

Leadership role. As middle manager, the principal's role in initiation, implementation, and continuation is central to the change and change process. Whether the change is a grass roots, teacher-sponsored initiative or a bureaucratically instituted change from a higher level source, the principal is expected to show leadership in several areas of the process. Despite a pivotal role in the change process, most principals have not been trained in this kind of leadership.

Change requires purposeful leadership, often demanding that the principal lead change in the school as an organization, while continuing to manage the operation of the school. Principals are being asked to blend change leadership -- i.e., articulate a vision, generate shared ownership, provide inspired direction, and develop evolutionary planning -- with the day-to-day and change management, where they need to negotiate demands and resource issues within the school environment and coordinate problem-solving and problem-coping.

All principals effective in the change process demonstrate active leadership, motivate staff and students, reach out into the community, and continually work to improve their schools. Their impact is felt through their actions: generation of solutions, fostering of long-term staff development, development of teacher commitment to implementing change, strengthening of the school's culture, stimulation and reinforcement of cultural change. Change-effective principals engage in frequent, direct communication about cultural norms, values, and beliefs, using symbols to express cultural values. These principals share power and responsibility with others. These are actions that impact the instructional and work climate of the school as an organization.

Even with these common general characteristics, the most important role fit is between the style of the principal, the subcultures within the school community, and the initiations and implementations under way. Specific innovations require more overt management activities, while holistic reforms can be managed through a series of direct and indirect interactions.

The four major tasks of effective principals in leading change are the same activities required of the principal during the unfolding change process:

- resource provider, funneling the necessary resources to the change process;
- instructional resource, maintaining instructional leadership and decision-making in the areas of curriculum and instruction;
- communicator, providing a sounding board and message relay system for the various levels of school system involved in the change; and
- visible presence, being available and interested in the process.

The combinations and interactions of these tasks vary during various stages of the change process. Initiation emphasizes the instructional resource and communicator. The implementation process makes the resource provider and visible presence roles more immediately critical while communicator and instructional resource activities become secondary. All four roles are present in continuation, but to a lesser degree.

Isolation. Remembering their middle management position in the school hierarchy -- and their inner circle relationship to change -- principals are in the middle of a highly complicated personal and organizational change process. They can experience conflict in change from their staff and/or the central administration. Principals tend to experience this conflict and/or uncertainty privately, maintaining an isolation that they have often helped to break down for their staff. Personal contact is a significant strategy in the change process for people at all levels of the process. A method for improving social contact to develop shared meaning for principals needs to be developed. "**...many other teachers and principals desire more social contact concerning professional matters, if it can be done in a supportive climate**" (authors' emphasis) (Fullan & Stiegelbauer, 1991, p. 166). Additionally, a principal can be in the uncomfortable situation of being expected by superiors to lead the implementation of a change which he or she does not understand, in which his or her staff is not interested or in which the staff is interested but for which the principal is unclear about how to assist or obtain resources.

Students

Because most change is ultimately directed at a change in student outcomes, students are a logical inclusion in the inner circle of change participants. Despite their logical inclusion, it was not until the 1980s that research even began to look at students as participants in their own education. To date little has been done to enhance the role of students as members of the school as an organization. As educational reform efforts have moved toward a constructivist approach to learning, this attention to the role of students in the change process has become even more important.

Because data is insufficient or lacking, it is necessary to infer what change means to students. The best conjecture is that change for students is indifference, confusion, temporary escape from boredom, heightened interest, and/or engagement in learning and school. Student confusion is a result of teacher and administration confusion about the innovation and the change process that is under way. The clearer new policies and programs are in the minds of educators, the more likely students are to experience the change as an ordinary part of the curriculum or school life.

A more proactive view of change for students would be to equip them with techniques that would insure facility for them in performing their new role in the change. This approach could reduce indifference and confusion. Any innovation that requires new activities on the part of the student will succeed or fail according to whether the student actually participates in the activity. Without guidelines and role play, for example, cooperative learning can be for students just a chance to visit with neighbors while accomplishing little learning.

Student participation is limited by their understanding and motivation to try what is expected of them. Previous experiences with innovation may not have been conducive to increasing their motivation or understanding. This new change may be just another chance for failure or for not knowing what is happening.

Innovations can be a temporary escape from the routine or boredom of school. To reduce this possibility, changes need to be made at two levels in concert: the instructional or classroom level, and at the level of the school as an organization. Changing the school as an organization has been the theme of many contemporary restructuring efforts and at the same time other efforts are directed at changes in pedagogical practice at the classroom level.

New approaches to learning. Cooperative learning and constructivist learning are two such pedagogical changes. Specifically in cooperative learning, students accustomed to competitive or individualistic instruction need to be retrained to understand and value working with others. New expectations of them as participants in this change are sharing ideas with others, listening to peers, completing work as part of a team, and taking responsibility for others as well as themselves. Constructivist learning is even more demanding of students as the earlier discussion on constructivism suggests.

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Changes at the level of the school as an organization not only provide improvement in instruction but also yield indirect improvements to students in the meaning of education. New organizational structures can result in cooperative learning experiences with businesses in the form of work-study partnerships, collaborative work cultures, active leadership, continuous improvement, and greater teacher skill and commitment. In general, schools can become a better place for learning for both adults and children.

Implications of change. The implications of change for students are many. First, students are recognized and treated as people who are effected by the change and change process. They need to be considered in the planning of the process. Second, students have limited power to bring about positive change, but they have considerable power to reject it.

Change requires cognitive and behavioral changes for students as well as staff. Consequently, the role relationship between teachers and students needs to change. The change is tied to the motivation for and understanding of the implementation activities. After all, the implementation activities are the means of achieving learning outcomes. It is necessary to think of students not only in terms of learning outcomes but also as the people being asked to become involved in new activities.

There is virtually no information on student opinions of specific innovations. In future research, it is important to consider explicitly how innovations are introduced to students and how student reactions will be obtained at that point and throughout the implementation. The more complex the change, the more student involvement required. This student involvement can and should include classroom and school wide data collection, and should include more than just a few student leaders. Involving students in the consideration of the meaning and purpose of specific changes and in new forms of day-to-day learning directly addresses knowledge skills and behaviors necessary for all students to become engaged in their own learning. Fullan and Stiegelbauer (1991) recommend,

> "Teachers who blend education and change, periodically discuss the meaning of activities with students, work on skills students need to participate in new educational reforms, and consider the relationship between old and new, will be going a long way in accomplishing some of the more complex cognitive and social educational objectives contained in the policy statements and curricula of most schools." (p. 190)

Other Local Change Participants

Other local change participants include district administrators, consultants to the district from without and within, and the community served by the school district, including parents, taxpayers, and school board members. All of these participants influence the change in some form or another. Either they are directing the change and are changed or changing themselves in relation to the innovation, or they are close to the people who are changing, the students, the

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teachers, or the principals. Many of these middle circle participants may think that they will not have to adjust their beliefs, but in actuality, they are not supporting the change if their beliefs are not in line with the shared vision of the inner circle. This can create strife within the district and create feelings invalidating the work of the change agents.

District administrator. The role of district administrator in the change process is twofold. First, it is to lead the development and execution of a system-wide approach to reform that explicitly addresses and takes into account all the causes for the change at the district, school, and classroom level. Second, the district administrator increases the basic capacity of the system to manage the change effectively. This means setting expectations and a tone for patterns of change to occur and providing the resources to be available to meet the expectations. It is important that the district administrator operate from a theory of change or the result may be fragmentation, overload of staff, and incoherence of programs. Uncritical and uncoordinated acceptance of too many different implementation efforts can lead to destructive interference, confusion, and chaos.

The district administrator's most crucial skill is communication. Two-way communication is necessary to eliminate misinterpretation and misunderstanding. Each individual's personal perceptions and concerns need to be aired. It is not enough for these top leaders to set the tone and pace of the communication climate, they must also participate in and value the interchange of ideas that needs to occur in building a shared vision. In addition, they must model what they value.

The vantage point of the district administrator is much wider than any other participant in either the inner or middle circle. His or her view must encompass all the participants in their multiple arenas. Reform is played out on four contested terrains: the classroom, the school, the collection of schools within a school system, and the school district within the community. The contests are different in each location and with each constituency.

Doing the right things at the district level to support and facilitate change in schools demands that district administrators focus on teaching and learning, create classroom and school conditions for collaborative teacher and principal professionalism, mobilize parents and community members in support of their schools, and use district resources to hire, promote, and support change through staffing. Change-minded district administrators orchestrate, pressure, and support continuous classroom and school improvement.

The reality is that this process needs long-term sustenance for 10 or more years. This period of time frequently translates into the tenure of two to three different superintendents. Therefore, it is the school board that sustains the process of change through its collective knowledge and action.

Consultants. As the change process has become more of a restructuring of schools, with more comprehensive goals and less of a single innovation activity, consultants have been used to fill in the gaps of local expertise. Consultants, either internal to the district or external to it, assist in charting and planning the course of action in the change process.

Internal consultants are a little researched entity. It is recognized that most work in unique settings with few commonalities. Expert internal consultants conceptualize their role as working with systems as well as with people. Their role includes

1. the development of support for the innovation;

2. the provision of technical assistance;

3. the clarification of the implementation process;

4. the increase of mastery, confidence, and ownership in the innovation;

5. the pursuit and documentation of the changes in practice; and

6. the provision of a complete record of the change.

This role is filled best when the consultant offers specific kinds of assistance rather than general, abstract advice and requires skillful negotiations between and among all levels of the change setting, from top level administrators to students. In interventions with teachers, consultants are much less direct and more two way than principals. Such teacher contacts are longer and more frequent. They consist of multiple actions and are more interactive in nature. Internal consultants work on multiple outcomes of an innovation simultaneously. They are more likely to address more fundamental and difficult outcomes.

External consultants, with a vantage point outside the system, often have a greater awareness of the new practices available and are able to choose among a range of alternatives that match local needs. Most ensure up-front that resources and facilities are available, as well as help plan implementation and continuation. They arrange for and conduct training.

With their wide variety of services, external consultants provide districts with change expertise that can impact all aspects of the change process. Their most difficult job is to determine how best to work within the local context and school conditions. The problems they face generally fall into four categories: availability of resources, the extent of tension among staff factions, the amount of staff turnover and disruptions, and staff expectations. From all this they are expected to develop an organizational meaning for change in a given system.

Fullan and Stiegelbauer (1991) summarize well the dilemma of involving a consultant, particularly one external to the system

> ". . . not to seek any outside help is to be more self-sufficient than the demands of educational change would allow. The primary task of the school district should be to develop its own internal capacity to assist and manage both the content and the process of change, relying selectively on external assistance to train insiders and to provide specific program expertise in combination with internal follow through." (p. 225)

Parents and the community. One clear and consistent message sounds from the studies on parents' relationships with schools. The closer a parent is to the education of his or her child, the greater the impact on the child's development and educational achievement. Direct contact with instruction, even if it is not at the grade level of the parent's child, is the critical factor. This contact provides an understanding of the curriculum, which assists the parent in developing an understanding of the school's vision and direction. Parent involvement in the classroom is more common in elementary and middle schools than at the secondary level, but noninstructional forms of involvement occur across all levels and provide some exposure to school mores.

Some schools actively encourage parental involvement with student learning, which often goes beyond the classroom walls to homework and reinforcement of school practices. To accomplish much with these activities, teachers and schools as a whole have responded to parental requests to provide guidance to parents in what needs to be done and how, by creating programs to educate parents. To do this teachers have reconceptualized their relationship with parents, viewing parents in collaborative terms and describing parents as assets to learning.

In reaching out to communities, five characteristics of outreach programs have been identified as critical:

"1. human resources (recruitment of community members in the school);

2. public relations (aggressive marketing);

3. fiscal resources (additional monies);

4. community services (involvement of students in the community);

5. building an identity (symbolic sense of identity with the community)" (from Wilson & Corcoran, 1988, as cited in Fullan & Stiegelbauer, 1991, p. 240-241).

School boards are community forums of, for, and by the people. While the opposition or support of a particular innovation is usually the target of parental or community action, it should be remembered that anyone interested in effective educational change works with or under the auspices of the school board and with the community to support the change at all levels of its operation.

Parents and community members are seriously interested in their schools. For the past five years Gallup polls for Phi Delta Kappan reveal that parents' lack of interest in schools and their child's education is a perceived as a problem in public schools by only six or seven percent of the public (Elam, 1991 & 1990; Elam & Gallup, 1989 & 1988; Gallup & Clark, 1987). In 1990 parents' lack of interest was seen as a problem by less than five percent of the people responding (Elam, 1990).

More Removed Change Participants

The multiple layers of government -- regional, state, and federal -- and all its associated policy bodies make up the outer circle of change participants. While perceived as outside of the school culture and its shared meaning of change, these agencies of government create conditions for change to which the school people must respond.

While there are many differences among various levels of government, there are several commonalities. Governments are responsible for protecting minorities and for providing quality and equity of education at the local level. They develop policies that compete and cooperate with local schools and school boards for what is perceived politically as good for children and for the country. As governmental staff try to oversee change generated by legislative and bureaucratic policy making, there are several things governmental agencies and their representatives can do to assist better implementation of governmental programs and policies. Fullan and Stiegelbauer (1991) suggest these mutually reinforcing considerations:

"1. compliance vs. capacity,

2. state-district relationships,

3. implementation planning and resources,

4. the preparation of government staff,

5. a focus on second-order change, and

6. an appreciation of complexity and persistence in the change process." (p. 282)

Compliance vs. capacity. Elmore (cited in Fullan & Stiegelbauer, 1991, p. 283) views the difference between compliance and capacity as a difference between willingness to comply and the ability to successfully deliver the service. Implementation is dependent upon delivery. If an agency responsible for compliance focuses exclusively on compliance, especially in the form of regulation, implementation can be limited. Tight regulation can result in more energy expended in surveillance with mounds of paper work and reporting, rather than in implementing the change. Attention is diverted from the local capacity to make improvements, and program delivery is further removed from the students it was conceived to help. As a rule of thumb, government staffers should ask if the local problem is one of competing priorities and lack of resources, skills, and leadership -- or capacity issues, or resistance to the program -- or a compliance issue. Capacity problems are not solved by surveillance methods.

State-district relationships. If producing reform is indeed active problem-solving, then personnel at district, state, and other levels need to interact to clarify policies and expectations. Often government personnel are unfamiliar with "conditions in the trenches" where the policy will need to be implemented. If policymakers and agency personnel, as well as district level administrators, ask en route what the idea or policy will look like in practice, many implementation problems would be solved before they were problems. By interacting with local district personnel to answer questions early on, government staff would recognize sincere efforts of compliance and develop an understanding of factors limiting compliance. Making the policy adoption process a two way street would improve policies and implementation.

Planning. Implementation is a complex process of bringing about change in practice. From a political perspective, before policy decisions are complete it is necessary to backward map the policy from practice to statement and reason through implementation problems. Also implicit here are the other supporting elements of the implementation process: monetary and technical resources, program development, and local and agency interaction.

Government staff preparation. Just as an ethos of change is necessary for schools to be effective and efficiently managed, so too is a climate of knowledge and understanding necessary in government agencies and among government personnel -- especially those most directly involved at the public-change interface -- for the meaning of the implementation to be clearly broadcast. Understanding the rationale used to shape a key decision can go a long way in selling it to the public. Often however, central or regional staffers are not privy to the necessary background and are lacking in understanding themselves. This failure can result from poor internal communication, frequent reorganization of personnel, and/or insufficient longevity of personnel in a particular role. Any and all of these reduce communication to and from the agency.

Second-order change. Focus on second-order change is a fancy way of saying that policies must be integrated to be effective. They need to focus on basic changes in teaching and learning, encompass the complete vision from policy formation to follow-through and revision, and use the synergy gathered from the combination to address the complex reform agenda that is part of the vision. Basic changes in teaching and learning are the focal point.

Complexity and persistence. They go hand-in-hand to produce the change that is being sought. Therefore, it is necessary for policymakers to temper their desires for a quick fix of the total educational process, with an understanding of the complexity of the change process (Anderson, 1992). While comprehensive change is possible, multifaceted and interrelated strategies within various timeframes are necessary. These strategies must be applied with persistence and evolutionary shaping. The role of government in reforming education should be as an impetus for engaging local districts in active local problem-solving. Governments are able to enlarge the problem-solving arena and provide pressure and support that force and reinforce local districts in their efforts to gain continuous improvements.

The Systemic Approach to Reform

While not a part of the educational change literature, the more encompassing systems perspective provides the cohesive conception necessary in mobilizing the processes of reform. The power of systems thinking is great and it fits the educational reform context; it deserves the reflection and experimentation required to utilize it. If we are to apply systems thinking to curriculum reform, it is essential to understand what it is, its applicability to educational situations, and how this thinking can inform educational change endeavors.

Systems Thinking Applied to Curriculum Reform

What is systems thinking? Systems thinking is what Senge (1990) calls the "fifth discipline" in his analysis of the "learning organization," and in fact, is the cornerstone of all the other "disciplines" in his characterization of dynamic and effective organizations. In his treatise on organizational theory, systems thinking is not only a conceptual framework for understanding organizations but a body of knowledge and collection of tools to use in influencing a system.

Systemic structures. A beginning point for a deep understanding of systems thinking is understanding systemic structures.

> "The term 'structure,' as used here, does not mean the 'logical structure' of a carefully developed argument or the reporting 'structure' as shown by an organization chart. Rather, 'systemic structure' is concerned with the key interrelationships that influence behavior over time. These are not interrelationships between people, but among key variables, such as population, natural resources, and food production in a developing country; or engineers' product ideas and technical and managerial know-how in a high-tech company." (Senge, 1990, p. 44)

In educational settings, these interrelationships exist among curriculum content, testing programs, and teacher decision-making in a curriculum reform endeavor; or among learning and teaching theories, student values, teacher beliefs, and administrative leadership in a school.

Systems complexity. Within a given system, e.g., a given school, these complex interrelationships produce a dynamic that in a way has a life of its own. As Meadows (as quoted in Senge, 1990, p. 43) notes, "The system causes its own behavior."

The complexity of such systems is the result of both the many <u>details</u> and the <u>dynamics</u> involved. In particular, this <u>dynamic complexity</u> is relevant to understanding educational situations.

> "The second type is <u>dynamic complexity</u>, situations where cause and effect are subtle, and where the effects over time of interventions are not obvious. Conventional forecasting, planning, and analysis methods are not equipped to deal with dynamic complexity. Mixing many ingredients in a stew involves detail complexity, as does following a complex set of instructions to assemble a machine, or taking inventory in a discount retail store. But none of these situations is especially complex dynamically.
>
> "When the same action has dramatically different effects in the short run and the long, there is dynamic complexity. When an action has one set of consequences locally and a very different set of consequences in another part of the system, there is dynamic complexity. When obvious interventions produce nonobvious consequences, there is dynamic complexity A gyroscope is a dynamically complex machine...." (Senge, 1990, p. 71)

The dynamic complexity of educational situations makes simple understandings or quick solutions to problems impossible. While this complexity may seem intuitively obvious, many professionals and politicians seem to overlook it when proposing educational reforms. This complexity is brought home by an exercise suggested by Senge (1990) in which a group of people covers a large wall with blank paper and begins to note all the variables they can identify in an educational setting along with their many interrelationships. The group then maps out all feedback relationships. After taking a half hour to identify key variables, write them on different parts of the paper, and try different feedback links, people generally realize it is not possible to figure out all the interactions (p. 281).

According to Schumacher (as cited in Senge, 1990, pp. 283-284) there are two kinds of problems: convergent problems and divergent problems. There is <u>a</u> solution for convergent problems. There is no "correct" solution for divergent problems. This is due to the nature of the problems themselves. How to educate children is a classic divergent problem.

The implications of this complexity are of major consequence when considering curriculum reform. **The apparent educational problems may well not be the real problems. The apparent causes of the problems are not likely to be the real causes. The obvious solutions are not likely to be effective and in addition they probably will have undesirable side effects.**

As a result, systemic thinking is not just something to <u>include</u> in one's approach to educational reform; it is a way of thinking that must be applied to the situation to begin to understand it well before even suggesting means of bringing about change.

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Using systems thinking for reform. Effective application of systems thinking to educational reform requires a disciplined approach.

"The essence of the discipline of systems thinking lies in a shift of mind:

* seeing interrelationships rather than linear cause-effect chains, and

* seeing processes of change rather than snapshots.

"The practice of systems thinking starts with understanding a simple concept called 'feedback' that shows how actions reinforce or counteract (balance) each other. It builds to learning to recognize types of 'structures' that recur again and again:..." (Senge, 1990, p. 73).

Putting the new understanding to work. The application of systems thinking to curriculum reform is not in finding the solutions that will solve the problem in a given setting. The situations are too complex and achieving success is an art. Systems thinking is an aid to this art. It can help in understanding the dynamic complexity of a given situation. It can pinpoint key interrelationships. It can help anticipate the unintended consequences of proposed actions.

> "**The real leverage in most management situations lies in understanding dynamic complexity, not detail complexity.....** Unfortunately, most 'systems analyses' focus on detail complexity not dynamic complexity. Simulations with thousands of variables and complex arrays of details can actually distract us from seeing patterns and major interrelationships. (Senge, 1990, p. 72)
>
> "The bottom line of systems thinking is leverage -- seeing where actions and changes in structures can lead to significant, enduring improvements. Often, leverage follows the principle of economy of means: where the best results come not from large-scale efforts but from small well-focused actions. Our nonsystemic ways of thinking are so damaging specifically because they consistently lead us to focus on low-leverage changes: we focus on symptoms where the stress is greatest. We repair or ameliorate the symptoms. But such efforts only make matters better in the short run, at best, and worse in the long run. (Senge, 1990, p. 114)
>
> "It's hard to disagree with the principle of leverage. But the leverage in most real-life systems, such as most organizations, is not obvious to most of the actors in those systems. They don't see the 'structures' underlying their actions. (Senge, 1990, p. 114)
>
> "Systems thinking finds its greatest benefits in helping us distinguish high- from low-leverage changes in highly complex situations. In effect, the art of systems

thinking lies in seeing through complexity to the underlying structures generating change. Systems thinking does not mean ignoring complexity." (Senge, 1990, p. 128)

Specific tools of systems thinking. A specific tool used in systems thinking is the application of what Senge (1990) calls systems archetypes to a given setting to identify key interrelationships. These archetypes, with labels such as "limits to growth" and "shifting the burden," are an aid for seeing interrelationships within the whole. Their purpose is to help identify structures and find the leverage, something that is hard to do in the midst of the crosscurrents and pressures of real-life situations. They have been used in our application of the Senge tools to curriculum reform, for example, to identify

1. limits to the move toward an applications-oriented science curriculum;
2. the side effects of certain short-term solutions to the problem of declining test scores;
3. potential erosion of commitment to long-term goals with the application of some short-term solutions to such goals as an increase in higher order thinking, greater gender equity, and more hands-on learning;
4. processes which reinforce unequal allocation of resources to competing educational programs; and
5. potential depletion, rather than wise management, of the limited resource of teacher time in some programs of educational reform.

The application of these tools provide context-specific information of value in specific situations faced by practitioners and policymakers initiating reform, or by researchers designing their research.

A Learning Organization

True reform will have occurred when the schools involved are not only reformed but have become reforming institutions, i.e., they are schools in which continuous progress and improvement are part of the "fabric of the place." In his explication of organizational theory, Senge refers to such an organization as a "learning organization." In Senge's (1990) analysis, there are five "disciplines" of the learning organization, with the "fifth discipline" -- the cornerstone of the others -- being the systems thinking discussed above. The four others are listed below along with brief descriptions.

PERSONAL MASTERY -- "... the discipline of continually clarifying and deepening our personal vision, of focusing our energies, of developing patience, and of seeing reality objectively... But surprisingly few organizations encourage

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the growth of their people in this manner." (Senge, 1990, p. 7)

MENTAL MODELS -- "... deeply ingrained assumptions, generalizations, or even pictures or images that influence how we understand the world and how we take action" (Senge, 1990, p. 8). In a learning organization considerable effective effort is devoted to developing shared mental models among its members.

BUILDING SHARED VISION -- a key idea about leadership that has been around for a long time. "When there is a genuine vision (as opposed to the all-too-familiar 'vision statement'), people excel and learn, not because they are told to, but because they want to." (Senge, 1990, p. 9)

TEAM LEARNING -- "When teams are truly learning, not only are they producing extraordinary results but the individual members are growing more rapidly than could have occurred otherwise.... Team learning is vital because teams, not individuals, are the fundamental learning unit in modern organizations. This is where 'the rubber meets the road'; unless teams can learn, the organization cannot learn." (Senge, 1990, p. 10)

There are some obvious similarities between aspects of the curriculum reforms under consideration in this review and the characteristics of a "learning organization." This similarity is not surprising; in both cases human learning -- in an individual and collective sense -- is the core of the matter. In one case it is the learning of students and in the other case the learning of an entire community of professionals, other staff, and students.

Delving much deeper into the characteristics of a learning organization is beyond the scope of this review, but it would be difficult to overemphasize their importance for the topic at hand. For the reader wishing to purse the matter further, attention is directed to Senge's "laws of the fifth discipline," his explication of the principles connected to the practice of his cornerstone discipline. (For a summary description of these "laws," the reader is referred to Senge, 1990, pp. 57-67.)

Becoming a "learning organization" is the ultimate solution to the school or district wanting to foster long-term curriculum reform.

Strategies for Making the Changes

There is an apparent need to address specific strategies for bringing about the curriculum reforms under consideration in this review. At the same time, there is an obvious tension between such a description of specific strategies and the need for such actions to be embedded within an organizational context having the systems thinking and other "disciplines" just described. If an organization prematurely jumps into some of the specific strategies without first developing its organizational capability for making the strategies effective, the odds of success are low. On the other hand, some moves toward curriculum reform may provide some of the matters of substance that need to be at the core of developing the organization's capability and be part of something done in manageable chunks with visible successes.

Therefore, the specific strategies described below are not presented as a laundry list of items from which a school can pick and choose simply on the basis of the attractiveness of individual items. They have promise in the context of an overall plan based on systemic thinking and in the context of a functioning organization having the characteristics of a "learning organization." This context reflects the spirit in which the following strategies are presented.

Finally, it should be noted that none of the more comprehensive strategies for bringing about change found in the research literature have been fully implemented in practice so it is hard to say if they will be successful. The strategies that have the most documentation of success are for small segments of the changes that are needed. Thus, this section identifies the strategies or component parts that seem most promising.

1. Teacher development with certain characteristics is necessary. Models do exist. The ones appearing to have considerable success involve the use of study groups and extensive modeling and coaching embedded within the life of the school day. These teacher development strategies are designed to help teachers develop roles such as the following as identified by Brown and Campione (1991): model expert behavior, monitor groups' understanding, engage in on-line diagnosis of emerging competence, push for deeper understanding, scaffold weaker student's emerging competence and fade into the background. Or similarly, those teacher roles identified by Bereiter and Scardamalia (1987): model and coach, making use of external prompts and peer cooperation to help students attain 'intentional learning' in which students activate prior knowledge; relate old knowledge to new knowledge; organize inconsonant bits of information; and assess conclusions before settling on them. In addition, Means and Knapp (1991) recommend that teachers encourage multiple approaches and make dialogue the central medium for teaching and learning.

In addition to the particular skills the teacher is to develop, several approaches to teacher development are necessary. Preservice teachers need to experience education and subject matter classes in which many of the strategies mentioned above are used and modeled. They must discuss the use, purpose, and implementation of these techniques and follow up with application of the methods in multiple practice situations designed to assist their understanding and use of the techniques.

While inservice teachers need similar experiences of seeing the techniques modeled; discussing their use, purpose and implementation; and applying the techniques with students in various settings, inservice teachers also need to reflect on their practice, reexamine their ideas about teaching and learning, and construct new metaphors for their new role in teaching.

2. Initiate state actions to change policy and perceptions. All policy changes must be directed toward the creation of an environment that enables the education system to provide high quality education for all students, i.e., a system focused on student learning outcomes. To this end, the Education Commission of the States (ECS, 1991) has identified areas of policy that are vital to the collaborative effort of reforming education. Leadership, inclusion, and organizational policies must redefine the environment of education to provide a broad base of leadership, to include people from both the educational system and the community, to define new roles, and to establish accountability. Leadership policies must address a) the need for a shared vision and comprehensive strategic plan; b) the expectation of change in leadership roles and responsibilities; and c) the need for waivers to remove barriers to new roles of leadership. Inclusion policies are needed "to prevent certain groups from being underserved and to involve people traditionally excluded from significant roles in the education system" (ECS, 1991, iii), by enfranchising parents and community members, encouraging interagency cooperation, and allowing business partnerships. Organizational policies must expand decision making beyond the traditional boundaries to encompass representatives of all groups in the school community and establish accountability practices to monitor the results.

Learning and renewal policies need to support individuals and the system itself. Learning policies must establish a commitment to the preparation of all students, set high expectations measured by the performance of desired outcomes, and provide instructional approaches that best teach essential skills. Renewal policies must promote growth, development, and renewal of individuals and groups; ensure availability of quality educators; and encourage ongoing evaluation of progress toward the shared vision.

Financial policies must focus on outcomes and serve as a catalyst for change. Restructuring requires funding up-front as well as reallocation of resources. Finance policies need to provide this funding, while encouraging innovation and focusing on learning outcomes.

3. **Change the culture of the school through the redesign of structures and regularities.** Both Sarason (1971) and Hargreaves (1988) recognize that the basis of many of the activities and practices that constitute teaching and classroom management is the culture of schooling in general and of a given school in particular. These practices have many outcomes which are not immediately obvious to those immersed in that culture. In addition, these outcomes -- both intended and unintended -- become part of the value system of the school. Because culture ties together practice, outcomes and values, the culture of a school is difficult to change, requiring those in the system to step back and view as novices a situation which they have actively built and supported. They must reevaluate old practices with an eye to new outcomes.

Hargreaves' (1998) example of transmission teaching clearly illustrates this point. Transmission teaching can be viewed as a successful method of managing large groups of students in a culture where domination strategies are a pervasive feature. He argues that to change this pattern, teachers and administrator must accept less control-centered educational purposes. He suggests that some people may regard transmission teaching as appropriate when resources are limited, it is compatible with a mandated curriculum, and it is protected by conditions of teacher isolation. Thus, he proposes an alternate view of why this behavior has persisted. He goes on to demonstrate how improved resources, a weakening of the public examination system (with a simultaneous strengthening of pupil-centered forms of assessment), improvement of systems of staff development and the creation of opportunities for collaboration are answers which are based on a sociological approach to understanding the conditions of teaching quality. He characterizes the official explanations as placing the blame for deficiencies on teachers and on those who train them rather than examining the characteristics of the environment in which teachers operate.

4. Build collaboration and reduce isolation. According to Rosenholtz (1989) the needed collaboration can be enhanced by accepting a definition of teaching in which it is an inherently difficult enterprise. If teaching is viewed as difficult, it becomes necessary and legitimate to seek professional assistance. Collaborative settings are further characterized by strong administrative or faculty leadership; a view of teaching as a collective rather than an individual enterprise; frequent requests and offers of assistance; and conditions which promote reasoned intentions, informed choices, and collective actions. Collaborative settings encourage the norms of mutual assistance and eagerness to learn, while sustaining norms of caring and tending to the needs of students. Existing practices place too much emphasis on management and order rather than the ideals of creativity, learning, and equity.

The workplace conditions which characterize continuous professional development include teachers engaging in frequent and increasingly precise talk about teaching practice, observing and providing each other with feedback, planning and developing instructional materials together, and teaching each other the practice of teaching. Merely providing time for teachers to be together is not the answer.

5. Change roles, responsibilities, relationships. The organizational environment is not the only source for cues about how to effect change. Personality theory assumes that an individual's behavior and response to change can be explained by unique characteristics of the individual (Spector, 1989). Several studies done on the developmental stages of teachers (Huberman, 1989; Spector, 1989; Katz, 1972) suggest that they progress through similar developmental concerns. In the first stage, often referred to as survival, the teacher is absorbed with self-adequacy and subject-matter adequacy. The teacher is in greatest need of understanding, direct support, and guidance at this time. The second stage, referred to variously as consolidation, stabilization and adjustment, is characterized by learning to cope with the school situation and school expectations. Teachers in this stage can still benefit from on-site help and may be more able to contribute to a collaborative setting. The third stage is characterized by maturation, with ventures into renewal through experimentation or activism. Teachers at this stage benefit greatly from attending conferences, joining professional associations, reading journals, and participation at teacher centers. If growth continues, the next stage is one of leadership. Teacher growth may take the form of providing inservice education, participating in degree programs, and continuing with the professional commitments of the previous stage. Teachers do not progress through the stages at a uniform rate; indeed some do not reach the higher levels. An understanding of the stages of teachers' growth provides a framework for the development of realistic expectations for staff developers to use as they help teachers met their needs and address their concerns.

Kaufman (1988) describes a similar view in which teacher development is influenced by three concentric spheres of context. The student is in the center circle where the student-teacher relationship defines the central goals of the practice of teaching. Working within this circle, the teacher is acquiring the tools of classroom management, mastering the curriculum, and perfecting instructional skills. The next wider circle contains colleagues; working within this circle the teacher is translating what she knows as a reflective practitioner so that it can be used by peers. Such translation may take the form of peer coaching or problem solving. Without a collegially based organizational culture, such interactions may not occur. The final circle is that of the profession. Within this circle the teacher is involved in professional organizations and constructing knowledge through action research. Most schools provide support for the teacher to learn in the student-centered context. The differentiated contexts of student, colleague, and profession could be used to develop a comprehensive staff development program for all teachers.

Nias (1987) examines the process of change at the individual level, using the psychology of perception to explain why teachers find it so difficult to change. Teaching involves perceptions, perspectives and judgments of the individual which cannot be easily changed without also changing the sense of self. The interactive requirements of teaching require the teacher to make constant judgments in response to sensory experience. These sensory experiences are selectively interpreted, however, based upon prior experiences and mental structures. Perception involves more than seeing; it also involves making sense out of the world. Educational innovation then is a matter of changing ways in which the teacher perceives; it involves the formation of new mental structures or the alteration of existing ones. This may not be so easy for several reasons. New material will be accepted only if it is compatible with existing mental structures or can be easily incorporated with minor adjustments to the structures. Many patterns of perception develop early and are not easily brought to consciousness; therefore, they are unavailable for discussion. Frames of reference are shared with other people, and thus, receive support from them. Finally, change is difficult because it may also involve emotions such as fear, anxiety, and loss of control.

Nias (1987) suggests the formation of free discussion groups in schools as a vehicle of change to provide people with alternative perspectives and heightening awareness of their own ego-centricity, as well as support for the loss felt by giving up old ways of perceiving. The goal of such groups is to develop common understandings and a language with shared meanings through communication. Several common barriers to effective groups arise due to occupational characteristics. The authority-dependency of many teachers arises from their assumption that those in authority possess important knowledge and that learning passes downwards from them. Many teachers find it difficult to listen; they spend all of their time doing the talking. Finally, in order to feel in control, teachers may avoid conflict with other adults. An additional barrier has to do with the nature of groups. Discussion groups are not to be confused with reference groups. Reference groups are made up of people who hold the same values, attitudes and opinions. They are more likely to hinder their members in the process of self-understanding and the adoption of new ideas than they are to promote reflection and personal change. Thus, natural groupings which occur in school settings, such as departments, may not be effective in bringing about change, if they are all of one mind.

6. Reallocate resources consistent with learning ou'comes, including time of personnel. Principal on the list of resources needing reexamination and reallocation for their contribution to constructivist learning and high quality learner outcomes for all students is time, particularly personnel time. Consensus building and decision making concerning what constitutes high quality learning outcomes require professional staff time to dialogue, argue, discuss and decide what changes are necessary and how those changes will be initiated. Staffs need time to investigate, plan, and practice strategies to initiate and implement each aspect of the reform process from the goals that go down on paper to their introduction in the classroom. Time is required to follow up, monitor, and adjust classroom modifications. Reflection on new practice, peer interaction and observation, mentoring other staff members, and constructing individual meaning of one's subject area and one's role are time intensive activities. Time becomes even more critical when the staff members' circle expands to include student-centered activities, such as providing students more feedback, individualizing lessons to facilitate student constructions of learning, reexamining lessons to accommodate student conceptions and misconceptions, or providing activities to alleviate misconceptions.

Creative approaches are necessary to solve the time crunch. Longer school years and/or longer school days in many cases are only a quick fix, because they are only part of the equation. The theme of "less is more" needs to be considered here. If personal energy is viewed as a resource, and balanced along with time, the time required for the change process to unfold and develop can be less draining on the individuals involved.

There are other resources that need reallocation. Tied to time, energy, and people are services. Change agents at all levels, but most especially teachers, need improved communications and communication services. Voice messaging, electronic bulletin boards and mailboxes, improved and expanded computer services, convenient fax availability, copying services, better access to research libraries are only part of what the business world and education business office takes for granted that is missing from the average teacher's world of experience.

More traditionally, teachers need instructional materials that are designed for use in constructivist learning. These materials may take many forms from textbooks to manipulatives, from library resources to museum exhibits. As teachers become more proficient in cultivating constructivist learning in their classrooms, many will develop materials of their own. Access to these teacher developed materials as well as commercially available materials is necessary. The development of shared decision making and site-based management are resulting in a better match of needs and resources when budgets are generated bottom up. They decrease turn-around time for fulfilling student needs and tailoring programs for the particular needs of individual schools rather than the generic needs of the system.

7. Change the assessment, curriculum and learning outcome content and relationships. The traditional view of the relationship among curriculum, learning outcomes and assessment is that curriculum drives what is learned and assessed. In reality, this relationship is not so simple and it often is out of balance. They need to be consistent with each other; it is sometimes said that they need to be <u>aligned</u>.

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Most assessment today is primarily summative assessment of student performance either for system accountability or individual certification. Such assessment is based on fact-oriented, multiple choice, standardized testing instruments that are largely developed by pyschometricians (Kane & Mitchell, 1992). The fact-orientation of these instruments is at odds with the thinking skills orientation of most reform efforts and the understanding of cognition represented by the constructivist model of teaching and learning.

> "...[I]n its form, multiple-choice testing promotes passive selection, not active production; it models 'right' and 'wrong' answers, an overly reductive view of knowledge; it depends on memorization and the recall of isolated facts; it focuses on what can be easily tested, rather than what is meaningful; and it trivializes learning by reducing the whole process to filling in ovoids." (Kane & Mitchell, 1992, p. 5)

By contrast, "performance assessments require active production -- and it is assumed, thinking -- by students, and frequently asks students to work in groups cooperatively" (Kane & Mitchell, 1992, p. 5). Performance assessments are presently being utilized for large-scale, accountability measures in several states with the specific intention of influencing instruction "in the direction of conceptual, holistic teaching and learning" (Kane & Mitchell, 1992, p. 6).

The requirement of these performance-based state tests has influenced classroom teachers to teach to the test and has resulted in elementary teachers in New York state using balances, electrical equipment, and other simple scientific tools with their students in an effort to prepare students for the grade 4 science manipulation skills test. Thus, assessment is no longer a passive component of the educational system, but rather as part of the reform effort, it can simultaneously assess and influence teaching (Kane & Mitchell, 1992).

The reforms in mathematics, science, and thinking across disciplines based on constructivist teaching and learning require an assessment model which is imbedded in the learning process while the present assessment model is predicated on a measurement model focused on terminal testing. Robert Mislevy best describes the mismatch:

> "It is only a slight exaggeration to describe the test theory that dominates educational measurement today as the application of twentieth century statistics to nineteenth century psychology.... It [traditional test theory] falls short for placement and instruction problems based on students' internal representations of systems, problem solving strategies, or reconfigurations of knowledge as they learn. Such applications demand different caricatures of ability -- more realistic ones that can express patterns suggested by recent developments in cognition and educational psychology." (Mislevy, as cited in Kane & Mitchell, 1992, p. 28)

8. Provide incentives for change. Incentives for change can focus at many levels of the process but might first be directed toward the immediate change participants. For students, incentives for change can include certificated outcomes in the form of guaranteed skills that are recognized by employers and colleges as standards for acceptance or simply satisfaction with the educational experience. For teachers, incentives for change may include a variety of both intrinsic and extrinsic rewards. In addition to financial incentives, it may include professional treatment, respect from students and community, recognition of a job well done, success with the materials or methods employed, and a voice in the decision making.

In recognition of the long-term nature of the systemic change process, celebrations of milestones along the way with all the change participants seems a reasonable acknowledgement of both the process and the people. While some rejoicing should be spontaneous, some celebrative rewards should be built into the time line and master plan.

9. Involve parents in new ways and build community connections to use the community as a learning resource. One important means of involvement for parents, business people, and community members is in determining learner outcomes toward which many of the changes will be directed. Their participation in the vision and its development helps to rally their support for the process.

In a description of Stanford's program of accelerated schools for the disadvantaged, Levin (1987) asks parents to set high expectations, support success, and encourage reading. These results need to be asked of every student, by every parent, grandparent, and community member. The community in Stanford's program provides support by offering extended day activities through the help of college students and senior citizens.

Maintaining clear two-way communication with parents and the community is essential to the goodwill and support needed for this lengthy process. Using parents to develop the school newsletter, interviewing members of the staff and student body, observing the process firsthand, and sharing that information with fellow parents could solidify support and keep everyone closer to the process.

With proper education in the form of workshops, parents can develop teaching and learning skills that can assist them in supervising and teaching their children at home in ways that reinforce what teachers are doing at school. There are several programs that encourage families to participate in mathematics and science activities as whole families. Whole and partial day formats of activities, games, and experiences are available for schools, parent organizations or civic clubs to sponsor.

10. Use a vision, action, reflection strategy. Anderson and Cox (1988) suggest the use of a strategy to better utilize the energy and diversity of the many groups and organizations active and interested in creating school reform. The strategy uses cooperative power in developing a new vision of education and building a new infrastructure to support and sustain the rebuilding effort. The first step is generating a shared vision of what the education system should look like and why. Next, the vision must become reality through productive and meaningful action throughout the system. As the action progresses, reflection on the sense of what is happening must occur.

Anderson and Cox (1988) warn

> "These are not linear steps, however. This approach is more like managing a three ring circus where the emphasis on each ring shifts based on complex orchestration, where the rings sometimes overlap and blend together, and, above all, where actions of those involved, though guided by a common sense of theme, are not fully predicted or controlled. Simply put, its management requires creative thinking." (p. 2)

THE CONTEXT FOR ONGOING REFORM

The previous section on the processes of reform portrayed an image of reform that is largely determined at the level of the individual school or school district. That image -- derived from the research literature -- is strong, and it is clear that much of what is necessary for such an image to reach reality cannot be imposed from outside the school or school district. Yet with the national concern for reforming education today, there is extensive attention to education at the national and state level with a large number of political and policy initiatives. How do the activities at these several levels relate and meld to foster curriculum reform?

Policies supportive of reform clearly are needed at all levels. Policymakers must attend to the research results described earlier and initiate actions at their particular level which are consistent with this research-based picture and make substantial contributes to the overall process of curriculum reform. They need to think systemicly about the entire picture of reform across all levels from the individual student to the nation. Whatever action is taken should make a positive contribution to the total system. For curriculum reform to be successful, support is needed at the local, state, and national levels, and that support must be consistent with the needs of the total system. Simplistic thinking needs to be replaced by systems thinking.

The National Professional Context

National professional groups, especially subject matter groups, have exerted a strong influence on curricula in recent decades. In the late fifties and sixties this influence was less through professional associations and more through the informal expressions of scientists' and mathematicians' opinions of what the curriculum should be, particularly through their influence upon National Science Foundation-funded curriculum development projects. Today, the influence is channeled more through professional groups such as the National Council of Teachers of Mathematics, the Mathematical Sciences Education Board of the National Academy of Sciences, the American Association for the Advancement of Science, and the National Science Teachers Association. Often through consensus-building processes, statements of standards and expectations have been developed that represent the thinking of scientists and mathematicians, or teachers of these subjects. In many cases, these position statements have had a strong influence on public and professional thinking about what education in these areas should be.

The thinking of scholars in various areas has influenced public and professional viewpoints about teaching higher order thinking as well. Examples of these influences are the writing of Lauren Resnick as published by the National Academy of Sciences, the work of Howard Gardner as reflected in some experimental schools, and the thinking of Theodore Sizer as portrayed in his writing and displayed in the Coalition of Essential Schools.

These professional and intellectual forces create a context in which curriculum reform is pursued. An individual school seeking reform in one of these areas likely will lay claim to such thinking as the inspiration for its reforms, or if not, go to considerable length to justify whatever actions they have taken that deviate from them. In the great majority of cases, it is the former; most everyone **claims** that their reforms are the ones recommended by such groups. Previously cited research, of course, clearly shows that many such claimed reforms do not really conform to these nationally recommended standards (e.g., Peterson, 1990; Ball, 1990, Cohen, 1990).

This situation raises a key research question: Can the individual school be the unit of change? The previously cited research about the curriculum reform efforts of the sixties casts grave doubt on the viability of creating reform from the national level, and the more recent literature on educational change points to the positive results of local initiative. Yet the research on the mathematics reforms in California just cited does not yield much optimism about a local process that does not have a validity check that reflects the national standards. The national context is clearly an important consideration in any research about curriculum reform in science, mathematics, or higher order thinking across the disciplines.

The National Political Context

A new program, America 2000,* initiated under former President Bush is an attempt to focus attention on the need for educational reform in many areas. Although there is a range of opinions within the educational community as to the probable outcomes of this program, America 2000 has directed public and professional attention to matters of educational reform.

America 2000 is the first comprehensive national education initiative (Doyle, 1991). Albert Shanker, president of the American Federation of Teachers, on the CBS program, Nightwatch, called it an historic event: "America 2000 is the first time the federal government has announced its commitment to all elementary and secondary schoolchildren" (Doyle, 1991, p. 187). According to Harold Howe II, a former U.S. commissioner of education and senior lecturer emeritus at the Harvard Graduate School of Education, Cambridge, MA,

> "In effect, America 2000 constitutes a bold move on the part of the executive branch of our federal government to exert a powerful force in the affairs of schools and to exert that force in the ways that reflect the particular ideology of the current President." (Howe, 1991, p. 193)

One of the major benefits seen from America 2000 was the focus in attention on our country's educational problems and the need for reform (Doyle 1991). The influence of the U.S. presidency came to bear on a major movement for educational change (Howe, 1991). This reform movement recognizes the importance of states and local communities in generating change.

> "America 2000 is a national strategy, not a federal program. It honors local control, relies on local initiative, affirms states and localities as the senior

*America 2000 is now known as GOALS 2000.

partners.... It recognizes that real educational reform happens community by community and school by school." (Howe, 1991 p. 193)

"Uncle Sam is ideally suited to act as a stimulus for change, as funder of 'venture capital,' and as the one party in the system with a truly national, global perspective" (Doyle, 1991, p. 190). He goes on to ask,

"What does Uncle Sam need to do? Provide the intellectual and political 'space', as well as access to resources, to design the 'school of the future' from the ground up. The New American Schools Development Corporation, funded by the private sector, has the flexibility and agility to move rapidly and decisively. It can act as 'venture capitalist' in ways the public sector could not." (Doyle, 1991, p. 190)

The major recommendations of America 2000 fall into four broad categories: strategies to help teachers, choice as a strategy for school improvement, "New American schools" and the "New American Schools Development Corporation," and "new world standards" and "American achievement tests" (Sewell, 1991).

Besides the focus on education in general, America 2000 has identified science and mathematics as one of the major areas of importance in education (Sewell, 1991). Goal number four of the national goals for education states that "By the year 2000, U.S. students will be first in the world in science and mathematics achievement" (Colorado 2000 Communities, 1991a, p. 20).

What does all of this mean for science and mathematics education reform? It means that the nation is focused on educational reform, and that science and mathematics have been singled out as an important part of that reform effort. It also means that the resources provided, including financial resources, of the federal government and any partnerships formed between agencies of the government and the private sector, are available for that reform effort. Science and mathematics reform projects also are envisioned as part of the model schools proposed in America 2000.

The State Government Context

The last decade has seen an unprecedented level of action directed toward educational reform on the part of state government, including governors, legislatures, and state departments of education. Although often spurred by such national initiatives as A Nation at Risk, the majority of these state actions seem to have been prompted by political imperatives within the given states. A high level of state action has existed for nearly a decade now and gives little indication of quickly disappearing at this point in time.

A recent boost to these state endeavors is the America 2000 program; individual states have been encouraged to take their own initiative for additional reforms. As the first state to formulate its own plan based on America 2000, Colorado serves as an example of how the national actions may be reflected at the state level. Colorado's plan for educational reform, Colorado 2000, will be described here as an example of how America 2000 is being worked out at the state level.

Colorado 2000 "is a community-by-community effort to help Colorado achieve America's education goals which were adopted by the President and the nation's governors. Colorado 2000 is supported by local and state government, education, business, labor, and civic leaders" (Colorado 2000 Communities, 1991a, p. 20). To achieve this goal, mathematics and science education need to be strengthened throughout the state with a special emphasis on the primary grades. The number of teachers with a substantive background in science and mathematics needs to increase, and there needs to be an increase in the number of both graduate and undergraduate students, especially women and minorities, in the areas of science, mathematics, and engineering.

In Colorado 2000 Communities, First Year Action Plan (1991b), the following priority recommendations are presented:

"A. Revise and expand the math-science-technology (MST) curriculum at every level so that it focuses on higher order thinking skills, critical thinking and problem-solving, rather than rote memorization and computation. The curriculum should provide many "hands on" active learning opportunities, and be application oriented, interdisciplinary and integrated with technology.

B. Update and maintain a high level of math, science and technology skills and knowledge in teachers, administrators and counselors through quality professional development programs. These programs should target pre-service teachers as well as those who are already employed as teachers. At the state level, this can be accomplished through the certification process and with technical assistance and increased resources, including technology, for staff development.

C. Create incentives to increase community involvement and support for learning and for high-science outcomes for all students and for reform efforts directed toward these ends.

D. Set high performance standards in math, science, and technology for all students.

E. Expand assessment methods to include authentic measures such as student portfolios, projects and performances that are alternatives to standardized tests.

F. Target resources to update and maintain facilities and equipment. This includes incorporating distance learning opportunities in classrooms, especially those in rural areas.

G. Challenge institutions of higher education to improve the quality of and participation in math-science-technology courses at the undergraduate level. Schools of Education have an especially important role in ensuring that all teachers have a high level of MST skills and knowledge.

H. Discuss issues of length of school day and year as well as instructional time on a statewide basis. Communities need to commit to increasing the emphasis on MST education in their schools." (pp. 19-20)

There obviously are many other recent state initiatives that predate America 2000, many of which have been widely recognized. California's curriculum frameworks and state assessment program are examples of initiatives receiving widespread attention in the state from which they come. Although the specific actions vary from state to state, it is clear that major initiatives have been launched in every state in the last decade.

The impact of actions such as these state-level initiatives, as well as national professional and political initiatives, will depend to a considerable extent upon <u>how</u> they are undertaken. A key question is whether or not they will be initiated in a manner that is consistent with systems thinking. Much the same could be said about local actions, most of which will claim allegiance to these state and/or national initiatives. Is systems thinking being applied at the local level as well?

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IMPLICATIONS FOR THE CURRICULUM REFORM PROJECT

The review of research presented in the preceding sections was conducted to provide a foundation for the work of the Curriculum Reform Project. This research had implications for the topics of commissioned papers selected for development, the character of the national conference on curriculum reform and assessment held in June 1992, the topics to be developed as "practical products" for practitioners and policymakers, and most importantly, the conceptual framework to be developed for a series of case studies of curriculum reform to be conducted in selected U.S. schools. These implications are developed below.

Commissioned Papers and National Conference

An early part of the curriculum reform project was the development of several commissioned papers and their presentation at a national conference where issues of curriculum reform discussed. The commissioned papers are a reflection of the literature reviewed here. In each case the author of the paper developed a statement about a specific issue raised in the review and extending our understanding of it in a research-grounded manner. These topics are listed below in three categories.

The Nature of Curriculum Reform

What is Involved in Teaching for Understanding at the Classroom Level?

Making Higher Order Thinking Part of the General Curriculum.

The Process of Reform

The Process of Reforming from the Top and the Bottom Simultaneously.

Using Extant Assessment Instruments or Programs to Measure the Impact of Curricular Reform on Higher Order Thinking.

Multiplying Successful Reforms: How Can Knowledge of Curricular Reforms Be Communicated to Policymakers and Practitioners Such That It Influences Practice?

Researching Curriculum Reform

Mapping the Results of Case Studies of Curricular Reform.

After further consideration of this literature review, additional papers may be developed by the project staff.

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Practical Products

Consideration of this literature review points to a number of crucial topics for practitioners and policymakers that need development. Examples of such topics, based on the literature review, are the following:

- What teacher and student belief changes are necessary for curriculum reform and how can these changes be fostered?

- What are viable approaches to local curriculum development?

- State-level means of fostering bottom-up curriculum reform.

- Local assessment approaches that foster constructivist approaches to teaching.

- How can teachers teach for understanding?

Selection of Sites for Case Studies

The research reviewed has important implications for the selection of sites for the case studies to be conducted as part of this project. A prominent implication is that one should not expect to find sites in which the full range of reforms are completely in place.

A key question is what criteria best identifies sites deserving study. Based on this review of the research literature on education reform, it appears the major reforms currently being promoted include the following (not in any priority order):

1. Enabling <u>all students</u> to learn to think is an educational goal that extends across the disciplines with particular attention in the subject areas of science and mathematics.

2. An important theme of the research literature on curriculum reform in science is a so-called constructivist approach to learning.

3. A related theme regarding the curriculum often goes under the label: "less is more."

4. Instead of presenting isolated facts, major attempts are made to focus on major themes of the subject matter and foster an integration of knowledge across the disciplines.

5. Constructivist learning requires constructivist approaches to teaching; rather than viewing students as passive recipients of information, teachers must focus on helping students construct understanding of concepts for themselves.

The task at hand is to find and study the leading cases of schools having one or more (preferably several) of these reforms firmly in place with evidence of positive outcomes for students.

Design of Case Studies

The literature review obviously has important implications for the design of the case studies, in particular the research questions to be addressed. Among the questions that stand out in a preliminary analysis of the literature are ones pertaining both to the substance of the reforms and the means by which the reforms were put in place.

With respect to the substance of the reforms attention will be given to both the content of the curriculum and the instruction by which students acquire it. In other words, the focus will be on the teaching/learning process.

With respect to the means by which the reforms are put in place, particular attention will be paid to systems thinking and the overall patterns of reform activities. Are successful reform sites appropriately described as "learning organizations?"

The substance of reform. The following questions are among those to be addressed with respect to the curriculum reforms themselves.

1. How are the sites defining their purposes and goals of reform with respect to students, teachers and the rest of the system?

2. What changes have occurred in the content of instruction?

3. What changes have occurred in the means of instruction, i.e., how are sites developing students' abilities to use a constructivist way of learning?

4. What has been the impact on student learning and what can be inferred from positive results about various ways of teaching science, mathematics, and higher order thinking?

5. How 'deep' are the changes, i.e, have the beliefs of students, parents and teachers changed?

6. To what extent is there a consensus on the nature of the changes that are being sought by the reformers, i.e., NCTM, AAAS, NSTA, and other national groups?

7. To what extent and how is the learning of thinking skills being transferred across disciplines?

8. How is the teaching of thinking skills being transferred across disciplines?

The means of reform. Attention also will be directed to study of how people got to where they are. This investigation will include looking for patterns of support throughout the system and examining how people monitor their progress toward desired goals.

1. What are the mechanisms for change?

2. How do implementation efforts play out in classrooms; i.e., what happens in classrooms when teachers embrace the spirit of the reforms espoused by the various national groups?

3. How are sites developing high quality content that meets the needs of their full range of students?

4. How are sites developing teachers' abilities to use a constructivist way of teaching?

5. What are the dynamics of change as viewed from a teaching and learning perspective among (a) students, (b) teachers, and (c) the rest of the system?

6. How are sites working out the trade-offs related to financial and expertise resources?

7. To what extent has the process of reform been top-down, bottom-up, or some combination of the two?

8. What are the means of system support? To what extent and in what ways are the system support strategies congruent with a constructivist way of viewing teaching and learning?

9. To what extent does the approach to change at the sites reflect systems thinking?

Future design work. The above questions are illustrative of key research foci for the case studies being done as part of this project. As the project progresses, these questions will be elaborated and the list extended. In doing so, this literature review will be the foundation for the design and planning work.

BIBLIOGRAPHY

Aldridge, Bill G. (1991) Scope, sequence, and coordination: A new synthesis for improving science education. Draft submitted to Journal of Science Education and Technology.

Aldridge, B.G. & Johnston, K.L. (1984). Trends and issues in science education. In Bybee, R.W., Carlson, J. & McCormack, A.J. (Eds.) NSTA 1984 Yearbook: Redesigning Science and Technology Education. Washington, DC: National Science Teachers Association.

America 2000: An Educational Strategy. (1991). Washington, DC: U.S. Department of Education.

American Association for the Advancement of Science (AAAS). (1989) Science for All Americans, Summary.

Anderson, B. & Cox, P. (1988). Configuring the Education System for a Shared Future: Collaborative Vision, Action, Reflection. Andover, MA: Regional Laboratory for Educational Improvement of the Northeast and Islands.

Anderson, B.L. (1985). State Testing and the Educational Community: Friends or Foes?, Educational Measurement: Issues and Practice, 4(2).

_______ (1989). Reformation of the Full Education System. Denver, CO: Education Commission of the States.

_______ (1991). Reflective Dialogue. A paper presented at the University of Wisconsin Conference on School Restructuring, October 1991.

_______ (1992). The complementary relationship between traditional and performance measures. A presentation at the annual meeting of the National Council on Measurement in Education.

Anderson, R.D. (1992). Perspectives on complexity: An essay on curricular reform. Journal of Research in Science Teaching, 29(8), 861-876.

_______ (1990). Policy decisions on improving science education: A cost-effectiveness analysis. Journal of Research in Science Teaching, 27(6), 553-574.

_______ (1987). An ethnographic study of curricular change: High school chemistry with an applied and societal orientation. A paper presented at the annual convention of the National Association for Research in Science Teaching. Washington, DC, April 23, 1987.

Anderson, R.D., et al. (1984) Improving Science and Mathematics Education: Costs and Effectiveness. Denver, CO: Colorado Department of Education. 145 pages.

_______ (1983). Science Education: A Meta-Analysis of Major Questions. Journal of Research in Science Teaching, 20(5), 379-385.

Anderson, R.D. (1983). A Consolidation and Appraisal of Science Meta-Analysis. Journal of Research in Science Teaching, 20(5), 497-509.

Arons, A.B. (1983). Achieving wider scientific literacy. Daedalus, 112(2), 91-122.

Arter, J. & Salmon, J. (1987). Assessing Higher Order Thinking Skills. Portland, OR: Northwest Regional Educational Laboratory.

Baker, E.L. (1990). Developing comprehensive assessments of higher order thinking. In G. Kulm (Ed.), Assessing higher order thinking in mathematics (pp. 7-20). Washington, DC: American Association for the Advancement of Science.

Ball, D.L. (1990). Reflections and deflections of policy: The case of Carol Turner. Educational Evaluation and Policy Analysis, 12(3), 263-275.

Banathy, B. (1991). Systems design of education: A journey to create the future. Englewood Cliffs, NJ: Educational Technology Publications.

Barba, R.H. (1990). Problem-solving pointers: Techniques can be taught. The Science Teacher, 57(7), 32-35.

Baron, J.B. & Sternberg, R.J. (1987). (Eds.) Teaching Thinking Skills: Theory and practice. New York: W. H. Freeman and Company.

Baxter, G.P.; Shavelson, R.J.; Goldman, S.R. & Pine, J. (1992). Evaluation of procedure-based scoring for hands-on science assessment. Journal of Educational Measurement, 29(1), 1-17.

Bereiter, C., & Scardamalia, M. (1987). An attainable version of high literacy: Approaches to teaching higher-order skills in reading and writing. Curriculum Inquiry, 17(1), 9-30.

Berryman, S. (1989). Economic change: The implications for student learning. NASSP Bulletin, 73(514), 59-70.

Bloom, B.S. (Ed.). (1956). Taxonomy of education objectives: The classification of educational goals. Handbook 1: Cognitive domain. New York: Longman.

ERIC

Blosser, P.E. (1990). Current Projects and Activities in K-12 Science Education Curriculum Development. ERIC/SMEAC Science Education Digest, No. 3.

_______ (1989). The Impact of Educational Reform on Science. ERIC/SMEAC Science Education Digest, No. 4.

Boyer, E. (1983). High school: A report on secondary education in America. New York: Harper and Row.

Boyer, E.L. (1988). The new agenda for the nation's schools. Educational Administration Quarterly, 24(3), 310-318.

Bransford, J.D.; Sherwood, R.D. & Sturdevant, T. (1987). Teaching thinking and problem solving. In Baron, J.B. & Sternberg, R.J. (Eds.) Teaching Thinking Skills: Theory and practice (pp. 162-181). New York: W. H. Freeman and Company.

Brown, A.L., & Campione, J. (1991). Communities of learning and thinking, or a context by any other name. In D. Kuhn (Ed.), Contributions to Human Development 21, 108-125.

Bryson, M., & Scardamalia, M. (1991). Teaching writing to students at risk for academic failure. In B. Means, C. Chelemer & M. S. Knapp (Eds.), Teaching advanced skills to at-risk students: Views from research and practice (pp. 255-276). San Francisco: Jossey-Bass.

Burkhardt, H. (1988). Teaching problem solving. In H. Burkhardt, S. Groves, A. Schoenfeld, & K. Stacey (Eds.), Problem-solving: A world view Proceedings of the problem solving theme group, ICME 5, (pp. 17-42). Nottingham: Shell Centre.

Bybee, R.; Buchwald, C.E.; Crissan, S.; Heil, D.R.; Kuerbis, P.J.; Matsuoto, C.; McInerney, J.D.; (1990). Science and Technology Education For the Middle Years: Frameworks for Curriculum and Instruction. The National Center for Improving Education, The Network, Washington, DC, and Biological Sciences Curriculum Study, Colorado Springs, CO.

California Department of Education (1985). Mathematics Framework for California Public Schools: Kindergarten Through Grade Twelve. Sacramento, CA: Author.

Carey, S. (1986). Cognitive science and science education. American Psychologist, 41(10), 1123-1130.

Carney, C.L. & Armstrong, R.W. (1985). Predictors of grades in general chemistry for allied health students. Journal of Chemical Education, 62(2), 127-129.

Carpenter, T.P. and Fennema, E.(1991). Research and cognitively guided instruction. In E. Fennema, T.P. Carpenter and S.J. Lamon (Eds.), Integrating Research on Teaching and Learning Mathematics, (pp. 1-16). Albany, NY: SUNY Press.

ERIC

Carpenter, T.P., Fennema, E., Peterson, P.L. and Carey, D.A. (1988). Teachers' pedagogical content knowledge of students' problem solving in elementary mathematics. Journal for Research in Mathematics Education, 19(5), 385-401.

Carpenter, T.P., Fennema, E., Peterson, P.L., Chiang, C.P., and Loef, M. (1989). Using knowledge of children's mathematics thinking in classroom teaching: An experimental study. American Educational Research Journal, 26(4), 499-531.

Chipman, S.F., Segal , J.W., & Glaser, R.(eds). (1985). Thinking and Learning Skills: Vol 2. Research and Open Questions. Hillsdale, NJ: Lawrence Erlbaum Associates.

Chipman, S.F., & Thomas, V.G. (1987). The participation of women and minorities in mathematical, scientific and technical fields. In C.B. Cazden (Ed.), Review of Research in Education (pp. 387-430). Washington, DC: American Educational Research Association.

Cobb, P. (1988). The Tension Between Theories of Learning and Instruction in Mathematics Education. Educational Psychologist, 23(2), 87-103.

Cobb, P., Yackel, E. and Wood, T. (1992). A constructivist alternative to the representational view of mind in mathematics education. Journal for Research in Mathematics Education, 23(1), 2-33.

_______ (1991a). Curriculum and teacher development: Psychological and anthropological perspectives. In E. Fennema, T.P. Carpenter and S.J. Lamon (Eds.), Integrating Research on Teaching and Learning Mathematics (pp. 83-120). Albany, NY: SUNY Press.

Cobb, P., Wood, T., Yackel, E. & McNeal, B. (1992). Characteristics of classroom mathematics traditions: An interactional analysis. American Educational Research Journal, 29(3), 573-604.

Cobb, P., Wood, T., Yackel, E., Nicholls, J., Wheatley, G., Trigatti, B. and Perlwitz, M. (1991b). Assessment of a problem-centered second-grade mathematics project. Journal for Research in Mathematics Education, 22(1), 3-29.

Cohen, D.K. (1990). A revolution in one classroom: The case of Mrs. Oublier. Educational Evaluation and Policy Analysis, 12,(3), 327-345.

_______ (1988). Teaching practice: Plus que--a change ... In P.W. Jackson (Ed), Contributing to Educational Change: Perspectives on Research and Practice (pp. 27-84). Berkeley, CA: McCutcheon.

Cohen, D.K. and Ball, D.L. (1990a). Relations between policy and practice: A commentary. Educational Evaluation and Policy Analysis, 12(3), 249-256.

_______ (1990b). Policy and practice: An overview. Educational Evaluation and Policy Analysis, 12(3), 347-353.

Cohen, M. (1989). Restructuring the system. Society, 26(4), 40-48.

Colorado 2000 Communities. (1991). Handbook: A Guide to Achieving the National Education Goals in Our Community. Denver, CO: Colorado 2000 Communities Initiative Steering Committee.

_______ (1991). First Year Action Plan: A Plan for Achieving the National Education Goals in Our Communities. Denver, CO: Colorado 2000 Communities Initiative Steering Committee.

Comer, J.P. (1989). Child development and education. Journal of Negro Education, 58(2), 125-139.

Commission on Teaching Standards for School Mathematics (1989). Curriculum and Evaluation Standards for School Mathematics. Reston, VA: National Council of Teachers of Mathematics.

_______ (1991). Professional Standards for Teaching Mathematics. Reston, VA: National Council of Teachers of Mathematics.

Confrey, J. (1990a). What constructivism implies for teaching. In R.B. Davis, C.A. Maher and N. Noddings (Eds.), Constructivist Views on the Teaching and Learning of Mathematics: Journal for Research in Mathematics Education, Monograph No. 4 (pp. 107-122). Reston, VA: NCTM.

Confrey, Jere. (1990b). A review of the research on student conceptions in mathematics, science, and programming. Review of Research in Education, 16, 3-47.

Cuban, L. (1984). Policy and research dilemmas in the teaching of reasoning: Unplanned designs. Review of Educational Research, 54(4), 655-681.

_______ (1988). Why do some reforms persist? Educational Administration Quarterly, 24(3), 329-335.

Darling-Hammond, L. (1990). Instructional policy into practice: the power of the bottom over the top. Educational Evaluation and Policy Analysis, 12(3), 233-241.

Darling-Hammond, L. & Hudson, L. (1990). Precollege science and mathematics teachers:

ERIC

Supply, demand and quality. In C.B. Cazden. (Ed) Review of Research in Education, 16 (pp. 223-261). Washington, DC: American Educational Research Association.

Davis, R.B. (1989). The culture of mathematics and the culture of schools. Journal of Mathematical Behavior, 8(2), 143-160.

Davis, R.B., Maher, C.A. and Noddings, N. (1990). (Eds.), Constructivist Views on the Teaching and Learning of Mathematics: Journal for Research in Mathematics Education Monograph, No. 4. Reston, VA: NCTM.

Delpit, L. (1988). The silenced dialogue: Power and pedagogy in education other peoples' children. Harvard Educational Review, 58(3), 280-298.

Dossey, J., Mullis, I., Lindquist, M. and Chambers, D. (1988). The Mathematics Report Card: Are We Measuring Up? Trends and Achievement Based on the 1986 National Assessment. Princeton, NJ: Educational Testing Service.

Doyle, D.P. (1991). America 2000. Phi Delta Kappan, 73(3), 185-191.

Doyle, W. (1988). Work in mathematics classes: The context of students' thinking during instruction. Educational Psychologist, 23(2), 167-180.

Duschl, R.A. (1989). A framework for applying history and philosophy of science to science education. A paper presented at the annual meeting of the National Association for Research in Science Teaching, San Francisco, CA, March 31, 1988.

_______ (1988). Abandoning the scientific legacy of science education. Science Education, 72(1), 51-62.

_______ (1985). Science education and philosophy of science twenty-five years of mutually exclusive development. School Science and Mathematics, 85(7), 541-555.

Duschl, R.A. & Gitomer, D.H. (1991). Epistomological perspectives on conceptual change: Implications for educational practice. Journal of Research in Science Teaching, 28(9), 839-858.

Educational Commission of the States (ECS). (1991). Exploring Policy Options to Restructure Education. Denver, CO: Educational Commission of the States.

Elam, S.M. (1991). The 23rd annual Gallup poll of the public's attitudes toward public schools. Phi Delta Kappan, 73(1), 41-56.

_______ (1990). The 22nd annual Gallup poll of the public's attitudes toward public schools. Phi Delta Kappan, 72(1), 41-55.

Elam, S.M. & Gallup, A.M. (1989). The 21st annual Gallup poll of the public's attitudes toward public schools. Phi Delta Kappan, 71(1), 41-56.

_______ (1988). The 20th annual Gallup poll of the public's attitudes toward public schools. Phi Delta Kappan, 70(1), 33-46.

Ennis, R.H. (1987). A taxonomy of critical thinking skills disposition and abilities. In Baron, J. & Sternberg, R.J. (Eds.) Teaching Thinking Skills: Theory and practice (pp. 9-26). New York: W.H. Freeman and Company.

Eylon, B. & Linn, M. (1988). Learning and instruction: An examination of four research perspectives in science education. Review of Educational Research, 58(3), 251-301.

Fass, P. S. (1989). Outside in: Minorities and the transformation of American education. New York: Oxford University Press.

Feinmen-Nemser, S. & Floden, R.E. (1986). The cultures of teaching. In M.C. Wittrock (Ed.), Handbook of research on teaching (3rd ed.) (pp. 505-526). New York: Macmillan Publishing Company.

Fensham, P.J. (1987). Science for all. Educational Leadership, 44(4), 18-23.

Flinders, D. J. ((1988). Teacher isolation and the new reform. Journal of Curriculum and Supervision, 4, 17-29.

Foster, A.G. (1991). When teachers initiate restructuring. Educational Leadership, 48(9), 27-30.

Foster, G. E. (1989). Cultivating the thinking skills of low achievers: A matter of equity. Journal of Negro Education, 58(4), 461-467.

Fullan, M.G. (1982). The Meaning of Educational Change. New York: Teachers College Press, Columbia University.

Fullan, M.G. & Steigelbauer, S. (1991). The New Meaning of Educational Change. New York: Teachers College Press, Columbia University.

Gallup, A.M. & Clark, D.L. (1987). The 19th annual Gallup poll of the public's attitudes toward public schools. Phi Delta Kappan, 69(1), 17-29.

Gamoram, A. & Berends, M. (1987). The effects of stratification in secondary schools: Synthesis of survey and ethnographic research. Review of Educational Research, 57, 415-435.

Garner, R. (1987). Metacognition and reading comprehension. Norwood, NJ: Ablex.

Garnett, P.J. & Tobin, K. (1988). Teaching for understanding: Exemplary practice in high school chemistry. Journal of Research in Science Teaching, 26(1), 1-14.

Goodlad, J. I. (1986). The learner at the world's center. Social Education, 50(6), 424-436.

Goodlad, J. (1984). A place called school: Prospects for the future. New York: McGraw-Hill.

Goodlad, J.I. & Klein, M. & associates. (1970). Behind the Classroom Door. Worthington, OH: Charles A. Jones.

Gough, D. (1991). Thinking about thinking. Research Roundup, 7(2), 1-4.

Gould, S. J. (1981). The Mismeasure of Man. New York: W. W. Norton & Company.

Hargreaves, A. (1988). Teaching quality: A sociological analysis. Journal of Curriculum Studies, 20, 211-231.

Hart, E.W. (1985). Is Discrete Mathematics the New Math of the eighties? Mathematics Teacher, 78(5), 334-337.

Harms, N.C. & Yager, R.E. (1981). What Research Says to the Science Teacher. Washington, DC: National Science Teachers Association.

Hawley, W. D. (1988). Missing pieces of the educational reform agenda: Or, why the first and second waves may miss the boat. Educational Administration Quarterly, 24(4), 416-437.

Hayden, R.W. & Rudolph, W.B. (1984). Will there be a new "New Math"? Journal of Curriculum Studies, 16(3), 311-316.

Heath, S. B. (1983). Ways with words: Language, life, and work in communities and classrooms. New York: Cambridge University Press.

Heid, M. K. (1988). Algebra with Computers: A Description and an Evaluation of Student Performance and Attitudes. (Report submitted to the State College Area School District Board of Education). State College: Pennsylvania State University.

Hickman, F.M. (1984). A case study of innovation. In R.W. Bybee, J. Carlson, J. & A.J. McCormack (Eds.) NSTA 1984 Yearbook: Redesigning Science and Technology Education. Washington, DC: National Science Teachers Association.

Hlebowitsh, P.S. & Hudson, S.E. (1991). Science education and the reawakening of the general education ideal. Science Education, 75(5), 563-576.

ERIC

Hoffman, K.M. (1989). The science of patterns: A practical philosophy of mathematics education. Paper presented at the annual meeting of the American Educational Research Association, San Francisco, CA.

Howe II, Harold (1991). A Bumpy Ride on Four Trains. Phi Delta Kappan, 73(3), 192-202.

Huberman, M. (1989). The professional life cycle of teachers. Teachers College Record, 91, 31-57.

Hurd, Paul DeHart (1985). Science Education for a New Age: The Reform Movement. NASSP Bulletin 69.

Hurd, P.D. (1986). Perspectives for the return of science education. Phi Delta Kappan, 67, 353-357.

Iran-Nejad, A. (1990). Active and dynamic self-regulation of learning processes. Review of Educational Research, 60(4), 573-602.

Jackson, P.W. (1983). The reform of science education: A cautionary tale. Daedalus, 112(2), 143-166.

Kane M. & Mitchell, R. (1992). Evaluating education reform: Assessment of student reform. Washington, DC: U.S. Department of Education, Office of Educational Research and Improvement.

Kansky, B. (1985). Looking back, I think I see the future.... Arithmetic Teacher, 32(5), 2-3.

Katz, L. G. (1972). Developmental stages of preschool teachers. Elementary School Journal, 73, 50-54.

Kaufman, B.A. (1988). Ecology of teacher development. Journal of Curriculum and Supervision, 4, 77-85.

Kieran, C. (1990). Cognitive Processes Involved in Learning School Algebra. In P. Nesher and J. Kilpatrick (Eds.) Mathematics and Cognition: A Research Synthesis by the International Group for the Psychology of Mathematics Education (pp. 96-112). New York: Cambridge University Press.

Kilpatrick, J. (1992). A history of research in mathematics education. In D.A. Grouws (Ed.). Handbook for Research on Mathematics Teaching and Learning (pp. 3-38). New York: Macmillan.

Kirst, M.W. (1988). Recent state education reform in the United States: Looking backward and forward. Educational Administration Quarterly, 24(3), 319-328.

ERIC

Klopfer, L.E. & Champagne, A.B. (1990). Ghosts of the crisis past. Science Education, 74(2), 133-154.

Knapp, M.S., Means, B., & Chelemer, C. (1991). Conclusion: Implementing new models for teaching advanced skills. In B. Means, C. Chelemer, & M.S. Knapp (Eds.), Teaching advanced skills to at-risk students: Views from research and practice (pp. 255-276). San Francisco: Jossey-Bass Publishers.

Koballa, T.R., Jr. (1985). Goals of science education. In D. Holdzkom & P.B. Lutz. (Eds.) Research Within Reach: Science Education. Washington, DC: National Association of Science Teachers.

Kuhn, T.S. (1970). The Structure of Scientific Revolutions. Chicago: University of Chicago Press.

Kyle, W.C., Jr. (1991). The reform agenda and science education: Hegemonic control vs. counterhegemony. Science Education, 75(4), 403-411.

_______ (1985). Curriculum development projects of the 1960's. In D. Holdzkom & P.B. Lutz (Eds.) Research Within Reach: Science Education. Washington, DC: National Association of Science Teachers.

Kyle, W.C., Jr.; Shymansky, J.A. & Alport, J.M. (1982). Alphabet soup science: A second look at NSF-funded science curriculum. The Science Teacher, 49(8), 49-53.

Lampert, M. (1991a). Connecting Mathematical Teaching and Learning. In E. Fennema, T.P. Carpenter and S.J. Lamon (Eds.), Integrating Research on Teaching and Learning Mathematics (pp. 121-152). Albany, NY: SUNY Press.

_______ (1991b). Teaching Mathematics One Problem at a Time. Paper presented at the annual meeting of the National Council of Teachers of Mathematics, New Orleans, LA.

_______ (1990). When the problem is not the problem and the solution is not the answer: Mathematical knowing and teaching. American Educational Research Journal, 27(1), 29-63.

_______ (1986). Knowing, doing and teaching multiplication. Cognition and Instruction, 3(4), 305-342.

Leinhardt, G. (1992). Presentation to annual convention of National Council of Teachers of Mathematics. Nashville, TN.

Levin, H.M. (1987). Accelerated school for disadvantaged students. Educational Leadership, 45, 19-21.

Linn, M.C. (1984). Redesigning science education: What is the role of science education research? In R.W. Bybee, J. Carlson, J. & A.J. McCormack (Eds.) NSTA 1984 Yearbook: Redesigning Science and Technology Education. Washington, DC: National Science Teachers Association.

Little, J. W. (1982). Norms of collegiality and experimentation: Workplace conditions of school success. American Educational Research Journal, 19, 325-340.

Lortie, D.C. (1975). Schoolteacher: A sociological study. Chicago: University of Chicago Press.

Loucks-Horsley, S., Brooks, J. G. Gannon; Carlson, M.O.; Kuerbis, P.; Marsh, D.; Padilla, M.; Pratt, H.; Smith, K. (1990). Developing and Supporting Teachers for Science Education in the Middle Years. Center for Improving Science Education, The Network, Washington, DC, Biological Sciences Curriculum Study, Colorado Springs, CO.

Loucks-Horsley, S.; Carlson, M.O.; Brink, L.H.; Horwitz, P.; Marsh, D.D.; Pratt, H.; Roy, K.R.; Worth, K. (1989). Developing and Supporting Teachers for Elementary School Science Education. National Center for Improving Science Education, The Network, Inc., Washington, DC, and Biological Sciences Curriculum Study, Colorado Springs, CO.

Loving, C.C. (1991). The scientific theory profile: A philosophy of science models for science teachers. Journal of Research in Science Teaching, 28(9), 823-838.

Marino, J.L. (1988). Between the lines of Boyer, Goodlad, and Sizer. English Journal, 77(2), 19-21.

Marzano, R.J.; Pickering, D.J. & Brandt, R.S. (1990). Integrating instructional programs through dimensions of learning. Educational Leadership, 47, 17-24.

Mathematical Sciences Education Board (1989). Everybody Counts: A Report to the Nation on the Future of Mathematics Education. Washington, DC.: National Research Council.

_______ (1990). Reshaping School Mathematics: A Philosophy and Framework for Curriculum. Washington, DC.: National Research Council.

McKnight, C.C., Crosswhite, F.J., Dossey, J.A., Kifer, E., Swafford, J.O., Travers, K.J., Cooney, T.J. (1987). The Underachieving Curriculum: Assessing U.S. School Mathematics From an International Perspective. Champaign, IL: Stipes.

Means, B., & Knapp, M.S. (1991). Introduction: Rethinking teaching for disadvantaged students. In B. Means, C. Chelemer, & M. S. Knapp (Eds.), Teaching advanced skills to at-risk students: Views from research and practice (pp. 1-26). San Francisco: Jossey-Bass Publishers.

Mehan, H., Hertweck, A., & Meihls, J.L. (1986). Handicapping the Handicapped. Stanford: Stanford University Press.

Metz, K.E. (1991). Development of explanation: Incremental and fundamental change in children's physics knowledge. Journal of Research in Science Teaching, 28(9), 785-798.

Mintzberg, H. (1979). The Structuring of Organizations. Englewood Cliffs, NJ: Prentice-Hall, Inc.

Mullis, I.V.S. & Jenkins, L.B. (1988). The Science Report Card: Elements of Risk and Recovery. Princeton, NJ: Educational Testing Service.

National Research Council. (1989). Everybody Counts: A Report to the Nation on the Future of Mathematics Education. Washington, DC: National Academy Press.

Nias, J. (1987). Seeing Anew: Teachers' Theories of Action. Victoria, Australia: Deakin Univer. y Press. (ERIC Document Reproduction Service No. ED 288 833).

Nickerson, R.S. (1988-1989). On improving thinking through instruction. In Cazden, C.B. (Ed.) Review of Research in Education, 15 (pp. 3-57). Washington, DC: American Educational Research Association.

Nickerson, R.S.; Perkins, D. & Smith. (1985). The Teaching of Thinking. Hillsdale, NJ: Erlbaum.

Noddings, N. (1990). Constructivism in mathematics education. In R.B. Davis, C.A. Maher and N. Noddings (Eds.) Constructivist Views on the Teaching and Learning of Mathematics: Journal for Research in Mathematics Education, Monograph No. 4. Reston, VA: NCTM.

Novak, J.D. (1991). Clarify with concept maps. A tool for students and teachers alike. The Science Teacher, 58(7), 44-49.

_______ (1988). Learning science and the science of learning. Studies in Science Education, 15, 77-101.

_______ (1984). Application of advances in learning theory and philosophy of science to the improvement of chemistry teaching. Journal of Chemical Education, 61, 607-612.

_______ (1977). An alternative to piagetian psychology for science and mathematics education. Science Education, 61(4), 453-477.

Novak, J.D. & Gowin, D.B. (1984). Learning How to Learn. New York: Cambridge University Press.

Nussbaum, J. & Novak, J.D. (1976). An assessment of children's concepts of the earth utilizing interviews. Science Education, 60(4), 535-550.

Oakes, J. (1990). Opportunities, achievement, and choice: Women and minority students in science and mathematics. In C.B. Cazden (Ed.), Review of Research in Education (pp. 153-222). Washington, DC: American Educational Research Association.

_______ (1988). Tracking in mathematics and science education: A Structural Contribution to Unequal Schooling. In L. Weis (Ed.), Class, Race & Gender in American Education. Albany, NY: SUNY Press.

_______ (1985). Keeping Track: How Schools Structure Inequality. New Haven, CT: Yale University Press.

Oakes, J., & Lipton, M. (1990). Making the best of schools. New Haven: Yale University Press.

Orlich, D.C. (1989). Education reforms: Mistakes, misconceptions, miscues. Phi Delta Kappan, 71(7), 512-517.

Osborne, R. & Wittrock, M. (1985). The generative model and its implications for science education. Studies in Science Education, 12, 59-87.

Palincsar, A., & Brown, A.L. (1989). Instruction for self-regulated reading. In L.B. Resnick & L.E. Klopfer (Eds.) Toward the thinking curriculum: Current cognitive research (pp. 19-39). Alexandria, VA: Association for Supervision and Curriculum Development.

Perkins, D.N. (1987). Knowledge as design: Teaching thinking through content. In Baron, J.B. & Sternberg, R.J. (Eds.) Teaching Thinking Skills: Theory and practice (pp. 62-83). New York: W.H. Freeman and Company.

Peterson, P.L. (1990a). The California study of elementary mathematics. Educational Evaluation and Policy Analysis, 12(3), 257-261.

_______ (1990b). Doing more in the same amount of time: The case of Cathy Swift. Educational Evaluation and Policy Analysis 12(3), 277-296.

Peterson, P.L., Fennema, E., Carpenter, T.P. and Loef, M. (1989). Teachers' pedagogical content beliefs in mathematics. Cognition and Instruction 6(1), 1-40.

Pines, A.L. & West, L.H.T. (1986). Conceptual understanding and science learning: An interpretation of research within a source of knowledge framework. Science Education, 70(5), 583-604.

Posner, G.J.; Strike, K.A.; Hewson, P.W. & Gertzog, W.A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. Science Education, 66(2), 211-227.

Prawat, R.S. (1989). Promoting access to knowledge, strategy, and disposition in students: A research snythesis. Review of Educational Research, 59(1), 1-41.

Presseisen, B. (1987). Thinking skills throughout the curriculum: A conceptual design. Bloomington, IN: Pi Lambda Theta, Inc.

Quellmalz, E.S. (1987). Developing reasoning skills. In Baron, J.B. & Sternberg, R.J. (Eds.) Teaching Thinking Skills: Theory and practice (pp. 86-105). New York: W.H. Freeman and Company.

Raizen, S.A.; Baron, J.B.; Champagne, A.B.; Haertel, E.; Mullis, I.V.S.; Oakes, J. (1989). Assessment in Elementary School Science Education. The National Center for Improving Science Education, The Network, Inc., Washington, DC, and Biological Sciences Curriculum Study, Colorado Springs, CO.

Reeve, R., Palincsar, A., & Brown, A. (1985). Everyday and academic thinking: Implications for learning and problem solving (Technical Report No. 349). Champaign, IL: Center for the Study of Reading, University of Illinois.

Reif, F. (1987). Instructional design, cognition, and technology: Applications to the teaching of science concepts. Journal of Research in Science Teaching, 24(4), 309-324.

Resnick, D.P., & Resnick, L.B. (1985). Standards, curriculum, and performance: A historical and comparative perspective. Educational Researcher, 14(4), 5-20.

Resnick, L.B. (1987). Education and learning to think. Washington, DC: National Academy Press.

_______ (1989). Introduction. In L. B. Resnick (Ed.), Knowing, learning and instruction: Essays in honor of Robert Glaser (pp. 1-24). Hillsdale, NJ: Lawrence Erlaum Associates Publishers.

Resnick, L.B., Bill, V.L., Lesgold, S.B., & Leer, M.N. (1991). Thinking in arithmetic class. In B. Means, C. Chelemer, & M. S. Knapp (Eds.), Teaching advanced skills to at-risk students: Views from research and practice (pp. 27-53). San Francisco: Jossey-Bass Publishers.

Resnick, L.B. & Klopfer, L.E. (1989). (Eds.) Toward the Thinking Curriculum: Current cognitive research. Washington, DC: Association for Supervision and Curriculum Development.

Richards, J. (1991). Mathematical discussions. In E. von Glaserfeld (Ed.), Radical Constructivism in Mathematics Education (pp. 13-51). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Romberg, T.A. and Carpenter, T.P. (1986). Research on Teaching and Learning Mathematics: Two disciplines of scientific inquiry. In M.C. Wittrock (Ed.), Handbook of Research on Teaching, 3rd Edition (pp. 850-873). New York: Macmillan.

Romberg, T.A., Zarinnia, E.A., & Collis, K.F. (1990). A new world view of assessment in mathematics. In G. Kulm (Ed.), Assessing higher order thinking in mathematics (pp. 21-38). Washington, DC: American Association for the Advancement of Science.

Rosenholtz, S.J. (1989). Workplace conditions that affect teacher quality and commitment: Implications for teacher induction programs. The Elementary School Journal, 89, 421-439.

Rutherford, F. James & Ahlgren, Andrew. (1990). Science for All Americans. New York: Oxford University Press.

Sarason, S.B. (1971). The Culture of the School and the Problem of Change. Boston: Allyn and Bacon.

Schauble, L., Klopfer, L.E. & Raghaven, K. (1991). Students' transition from an engineering model to a science model for experimentation. Journal of Research in Science Teaching, 28(9), 859-882.

Schoenfeld, A.H. (Forthcoming). Reflections on Doing and Teaching Mathematics. To appear in A.H. Schoenfeld (Ed.), Mathematical Thinking and Problem Solving.

_______ (1992a). Radical constructivism and the pragmatics of instruction—A review of Radical Constructivism in Mathematics Education, Edited by Ernst von Glaserfeld. Journal for Research in Mathematics Education, 23(3), 290-295.

_______ (1992b). Learning to Think Mathematically: Problem Solving, Metacognition, and Sense-Making in Mathematics. To appear in D. Grouws (Ed.), Handbook for Research on Mathematics Teaching and Learning (pp. 334-370). New York: Macmillan.

_______ (draft, 1990). Learning to think mathematically: Problem solving, metacognition, and sense-making in mathematics. In D. Grouws (Ed.), Handbook for Research on Mathematics Teaching and Learning. New York: Macmillan.

_______ (1989). Reflections on "A Practical Philosophy." Paper presented at the annual meeting of the American Educational Research Association, San Francisco, CA.

_______ (1988). When good teaching leads to bad results: The disasters of well-taught mathematics courses. Educational Psychologist 23(2), 145-166.

_______ (Ed.) (1987). Cognitive Science and Mathematics Education. Hillsdale, NJ: Lawrence Erlbaum Associates, Publishers.

_______ (1985). Mathematical Problem Solving. Orlando, FL: Academic Press.

Segal, J.W., Chipman, S.F., & Glaser, R. (eds). (1985). Thinking and Learning Skills: Vol 1. Relating Instruction to Research. Hillsdale, NJ: Lawrence Erlbaum Associates.

Senge, P. (1990). The Fifth Discipline: The Art and Practice of the Learning Organization. New York: Doubleday.

Sewell, Gilbert T. (1991). America 2000, An Appraisal. Phi Delta Kappan 73(3), 204-209.

Shapiro B.L. (1989). What children bring to light: Giving high status to learners' views and actions in science. Science Education 73(6), 711-733.

Shavelson, R.J.; Baxter, G.P.; Pine, J.; Yure, J.; Goldman, S.R. & Smith, B. (1991). Alternative technologies for large scale science assessment: Instrument of education reform. School Effectiveness and School Improvement 2(2), 97-114.

Sheets, C. and Heid, M.K. (1990). Integrating computers as tools in mathematics curricula (Grades 9-13): Portraits of group interactions. In N. Davidson (Ed.) Cooperative Learning in Mathematics: A Handbook for Teachers (pp. 265-294). Menlo Park, CA: Addison-Wesley.

Shepard, L.A. (1989). Why we need better assessments. Educational Leadership, 46(7), 4-5.

Shymansky, J.A.; Hedges, L.V. & Woodworth, G. (1990). A reassessment of the effects of inquiry-based science curricula of the 60's on student performance. Journal of Research in Science Teaching, 27(2), 127-144.

Shymansky, J. A., Kyle, W.C., and Alport, J. M. (1983). The Effects of New Science Curricula on Student Performance. Journal of Research in Teaching 20(5), 387-404.

Shymansky, J.A., and Kyle, W.C. (1990). Establishing a Research Agenda: Critical Issues of Science Curriculum Reform. Report of a conference held April 8, 1990.

Sizer, T. (1991). Horace's school: Redesigning the American high school. New York: Houghton Mifflin.

Sizer, T. (1984). Horace's compromise: The dilemma of the American high school. Boston: Houghton Mifflin.

Songer, N.B. & Linn, M.C. (1991). How do students' views of science influence knowledge integration? Journal of Research in Science Teaching, 28(9), 761-784.

Spady, W.G. & Marshall, K.J. (1991). Beyond traditional outcome-based education. Educational Leadership, 49(2), 67-72.

Spector, B.S. (1989). Empowering Teachers: Survival and Development. Dubuque, Iowa: Kendall/Hunt Publishing Company.

Stake, R.E. & Easley, J.A. (1978). Case Studies in Science Education. Urbana-Champaign, IL: Center for Instructional Research and Curriculum Evaluation and Committee on Culture and Cognition.

Steen, L.A. (1988). The science of patterns. Science, 240(29 April), 611-616.

Sternberg, R.J. (1987). Questions and answers about the nature and teaching of thinking skills. In Baron, J.B. & Sternberg, R.J. (1987). (Eds.) Teaching Thinking Skills: Theory and practice (pp. 251-259). New York: W. H. Freeman and Company.

Stiggins, R.J. (1991). Facing the challenges of a new era of educational assessment. Applied Measurement in Education, 4.

Stiggins, R.J.; Rubel, E. & Quellmalz, E. (1988). Measuring Thinking Skills in the Classroom. Washington, DC: National Education Association.

Stodolsky, S.S. and Hedges, L.V. (1990). The role of evaluation in the university of Chicago school mathematics project. In I. Wirszup and R. Streit (Eds.), Developments in School Mathematics Around the World, Vol. 2. Proceedings of the Second UCSMP International Conference on Mathematics Education (pp. 411-422). Reston, VA: NCTM.

Suarez, R.; Mills, R. & Stewart, D. (1987). Sanity, Insanity and Common Sense. New York: Fawcett Columbine.

Timar, T. (1989). The politics of school restructuring. Phi Delta Kappan, 71(4), 265-275.

Timar, T. & Kirp, D.L. (1989). Education reform in the 1980's: Lessons from the states. Phi Delta Kappan, 71(7), 504-511.

Tobias, S. (1990). They're Not Dumb, They're Different: Stalking the Second Tier. Tucson, AZ: Research Corporation.

Tobin, K. (1990). Changing metaphors and beliefs: A master switch for teaching? Theory Into Practice, 29(2), 122-127.

Tobin, K. & Espinet, M. (1989). Impediments to change: Applications of coaching in high school science teaching. Journal of Research in Science, 26(2), 105-120.

Tobin, K. & Espinet, M., Byrd, S.E., & Adams, D. (1988). Alternative perspectives of effective science teaching. Science Education, 72(4), 433-451.

Tobin, K. & Fraser, B.J. (1990). What does it mean to be an exemplary science teacher? Journal of Research in Science Teaching, 27(1), 3-25.

Usiskin, Z. (1990). The beliefs underlying UCSMP. In I. Wirszup and R. Streit (Eds.), Developments in School Mathematics Around the World, Vol. 2. Proceedings of the Second UCSMP International Conference on Mathematics Education (pp. 343-357). Reston, VA: NCTM.

von Glaserfeld, E. (Ed.) (1991). Radical Constructivism in Mathematics Education. Dordretch, The Netherlands: Kluwer Academic Publishers.

_______ (1989). Cognition, construction of knowledge, and teaching. Syntheses, 80, 121-140.

_______ (1987). Learning as a Constructive Activity. In C. Janvier (Ed.), Problems of Representation in the Teaching and Learning of Mathematics, (pp. 3-18). Hillsdale, NJ: Lawrence Erlbaum Associates, Publishers.

Vosniadou, S. & Brewer, W.F. (1987). Theories of knowledge restructuring on development. Review of Educational Research, 57(1), 51-67.

Wandersee, J.H. (1990). Concept mapping and the cartography of cognition. Journal of Research in Science Teaching, 27, 923-936.

_______ (1987). Drawing concept circles: A new way to teach and test students. Science Activities, 24(4), 9-20.

Welch, W. (1979). Twenty years of science curriculum development. In D. Berliner (Ed.), Review of Research in Education, vol 7. Washington, DC: American Educational Research Association.

Wiemers, N. J. (1990). Transformation and accommodation: A case study of Joe Scott. Educational Evaluation and Policy, 12(3), 297-308.

Wiggins, Grant. (1989). Teaching to the (Authentic) Test. Educational Leadership.

Wilson, S. M. (1990). A conflict of interests: The case of Mark Black. Educational Evaluation and Policy Analysis, 12(3), 309-326.

Woditsch, G. A. & Schmittroth, J. (1991). The Thoughtful Teacher's Guide to Thinking Skills. Hillsdale, NJ: Lawrence Erlbaum Associates, Publishers.

Wolf, D.P. and Pistone, N. (1991). Taking Full Measure: Rethinking Assessment Through the Arts. New York, NY: College Entrance Examination Board.

Wolf, D., Bixby, J., Glenn III, J., & Gardner, H. (1991). To use their minds well: Investigation new forms of student assessment. Review of Research in Education, 17, 31-74.

Wood, T.; Cobb, P. & Yackel, E. (1991). Change in teaching mathematics: A case study. American Education Research Journal, 28(3), 587-616.

Yager, R.E. (1992). Viewpoint: What we did not learn from the 60s about science curriculum reform. Journal of Research in Science Teaching, 29(8), 905-910.

_______ (1991). The constructivist learning model: Towards real reform in science education. The Science Teacher, 58(6), 52-57.

_______ (1984). Science and technology in general education. In R.W. Bybee, J. Carlson & A.J. McCormack (Eds.), NSTA 1984 Yearbook: Redesigning Science and Technology Education. Washington, DC: National Science Teachers Association.

Yager, R.E. & Krajcik, J.S. (1989). Success of students in a college physics course with and without experiencing a high school course. Journal of Research in Science Teaching, 26(7), 599-608.

Yager, R.E. & Penick, J.E. (1987). Resolving the crisis in science education: Understanding before resolution. Science Education, 71(1), 49-55.

Yager, R.E., Snider, B., & Krajcik, J. (1988). Relative success in college chemistry for students who experienced a high school course in chemistry and those who had not. Journal of Research in Science Teaching, 25(5), 385-394.

Zahorik, J.A. (1991). Teaching style and textbooks. Teaching and Teacher Education, 7(2), 185-196.

Zarinnia, E.A., & Romberg, T.A. (1987). A new world view and its impact on school mathematics. In T.A. Romberg & D.M. Stewart (Eds.), The Monitoring of School Mathematics: Background Paper. Vol. 1: The Monitoring Project and Mathematics Curriculum (pp. 21-61). Madison, WI: Wisconsin Center for Educational Research.

Zbiek, R.M. and Heid, M.K. (1990). The skateboard experiment: Math modeling for beginning algebra. The Computing Teacher, 18, 32-36.

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